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BASIC HORTICULTURE

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Basic
HORTICULTURE

by Victor R. Gardner

PROFESSOR OF HORTICULTURE
MICHIGAN STATE COLLEGE

THE MACMILLAN COMPANY · NEW YORK

1942

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PREFACE

In any beginning course in horticulture the student must acquire a certain fund of factual information. This should be valuable in itself, acquainting him with many kinds of fruit, vegetable, and ornamental plants and with their methods of culture. It is more important, however, that the student acquire a real understanding of plants — their structure, how they grow, and the way in which they react to different environments. If he comes to understand plants, he will be able to solve for himself problems that are sure to arise some time later and to which the specific answers were not provided in his formal course of instruction or, if provided, have been forgotten. In brief, the real objective should be to train the student to use his head, to think for himself, rather than just to remember. This being the case, there is probably no one set of facts or specific body of information with which the student must be provided. The instructor has a large volume and a wide range from which to choose. If he is located in a southern or western state, he may employ substantially different materials than he would use in a northern or eastern state and still give the student essentially the same training. The factual information and illustrative material included in this text are not presented as being any better for teaching a course in basic horticulture than entirely different material that might be chosen by another. They simply represent what the author has found useful in his own presentation of the subject.

The questions and problems at the end of the several chapters are from among those that the author has found useful, not so much in testing what the student has acquired in the way of information as in training him to *utilize* that information in the solution of practical problems. He has found that the student who is able to answer satisfactorily all of these questions, or even the few that are printed in heavy type, has a good grasp of the subject.

ACKNOWLEDGMENTS

Appreciation is expressed to a number of my associates — Messrs. R. E. Marshall, C. E. Russell, H. L. Seaton, K. C. Barrons, N. L.

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V. R. Gardner

East Lansing, Michigan
June, 1942

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BASIC HORTICULTURE

CHAPTER I

THE PLACE OF HORTICULTURE IN AMERICAN AGRICULTURE

STUDENTS who elect or who are required to take a course in horticulture should learn something about what it includes, the place that it occupies in the field of agriculture, and something of its relative importance as compared with the other branches of the industry.

HORTICULTURE DEFINED

There is, however, no hard and fast line separating horticultural crops or plants from those that are classified otherwise or elsewhere. Literally the word *horticulture* means "garden culture" or the "culture of garden crops and plants," and this implies cultivation within rather restricted areas. No one, however, has been able to say just how restricted the area must be to be called a *garden* or how extensive it must be to be called a *field*. In China and India the natives cultivate rice in small paddocks or plots, yet the world over rice is considered as a field crop. In California there are single vineyards of over 3,000 acres, but the grape is universally classified as a horticultural crop. Obviously the division line between horticultural and agronomic or field enterprises cannot be based on size of the areas or units devoted to them. In some instances, for example, with potatoes in Maine and Michigan, the crop is regarded as a field crop if grown extensively — that is, in large units — and as a horticultural crop if grown on a smaller scale, as in most states. In other instances, the crop is classified as belonging in one field of agriculture or in another, depending on the way in which, or the purpose for which, it is grown. Thus, Kentucky bluegrass in a pasture is considered a field crop; as part of a lawn mixture, it is considered a horticultural crop. Pine nuts, Brazil nuts, and pecans from native trees are classified as forest products; when pecans are harvested from either grafted native trees or from artificially planted trees, they are classified as horticultural products. In some areas most of the cacti are regarded as weeds; in some they are rendered serviceable as a stock food by burning off their spines and spicules; a few, such as the Indian fig (*Opuntia ficus-indica*), provide edible fruits; finally, they are cultivated for ornament in many gardens and greenhouses. Thus, they classify as weeds, forage crops, fruits, and ornamentals, depending on where and how they are grown and utilized. A comparatively large percentage of horticultural plants are set singly or in hills, or if grown in "solid" rows, they are so spaced that there is little competition between them. Most field crops, on the other hand, are seeded or planted more thickly and grown more or less *en masse;* they entirely cover the ground, and there is much crowding and competition between them. There are, however, many exceptions. Thus, field corn is grown in hills or well spaced in drilled rows, whereas lawn grasses are seeded even more thickly than pastures or meadows.

In view of such considerations as have just been cited, it is obvious that no exact statement can be made to the effect that horticulture comprises some definite percentage of agricultural industry or effort or science. If the question were considered from the standpoint of acreage devoted to the culture of horticultural crops compared with the acreage devoted to other crops, the answer would be one thing. If considered from the standpoint of sales value of the crops, it would be quite different; if viewed from the standpoint of number of kinds of crops or products grown, or amounts of labor employed, or if comparisons were made on the basis of any one of many other standards, still different answers would be obtained. As no one yardstick is comprehensive, so none is entirely accurate. Nevertheless, several comparisons may be useful in obtaining some perspective of the situation.

HORTICULTURE'S CONTRIBUTION TO THE DIET

A number of estimates have been made of the dietary requirements of the average family of 4 to 4.5 persons, and these have been checked with records of foods actually consumed. They naturally vary greatly with the section of the country, with economic status and living standards, with individual preferences, and with many other conditions. The following figures, however, approximate rather closely what authorities consider adequate quantities for the maintenance of reasonably high dietary standards for a year:

	Amounts	Values *
Cereal Products		
Bread	1,000 lbs.	$ 50
Flour	225 lbs.	10
Cereals	250 lbs.	10
Meats, Fats, and Oils	550 lbs.	110
Eggs	100 doz.	30
Milk (and cream, estimated as milk)	1,500 qts.	150
Sugar, Syrup, etc.	200 lbs.	10
Horticultural Products		
Potatoes (Irish and Sweet)	1,000 lbs.	10
Vegetables	1,500 lbs.	50
Fruits	500 lbs.	25
Coffee, tea, spices, etc.	50 lbs.	15
		$470

* These estimated values are subject to considerable variation from place to place and time to time. On the whole, however, price changes within one group do not long run counter to those in the others. Consequently, the *relative* values indicated are close enough for the comparisons that are intended.

If these estimated averages may be considered as approximately correct, horticultural products constitute a little over a third of the diet by weight and a little more than a fifth of its cost. On the other hand, the total acreage required to produce the horticultural third (by weight) of the diet requires less than 10 per cent of the acreage required for meeting the entire food supply, for most horticultural crops are raised with intensive methods. During the last several decades both fruits and vegetables, along with dairy products, have come to occupy a more prominent place in the diet, and they are relatively more prominent in the diet of those who are on high standards than in the food of those who must subsist on low dietary levels. Some idea of the place of horticultural products in the diet is afforded by the dinner menu reproduced in Figure 1.

Approximately 10 per cent of the cultivatable crop land of the United States from which crops are harvested is devoted to the production of fiber for clothing or for various industrial uses, and perhaps half of the grazing land is devoted to the production of fiber and hides used for apparel. Consequently, the position of horticultural products in the diet is not an accurate measure of its relative importance in agriculture from the standpoint of either acreage or total value of crop. On the other hand, most horticultural crops are grown intensively; they do not lend themselves to the use of mechanized equipment in their culture to the same extent as forage, grains, and fibers; they demand more hand labor and, consequently, provide employment for a much larger number of people than the acreage devoted to them might at first suggest.

DINNER

Chilled Tomato Juice   Sauerkraut Juice
Pineapple Juice   Fruit Cup   Grapefruit Juice
Cream of Tomato Soup   Fresh Vegetable Soup

Broiled Chinook Salmon, Maitre D'Hotel
Ragout of Beef Tenderloin and Mushrooms in Casserole
Spaghetti with Chicken Livers and Mushrooms
One Grilled Pork Chop with Fried Apple Ring

Mashed Potatoes   New Parsley Potatoes
New Harvard Beets or Garden Peas
or Chiffonade Salad

Fruit Jello Chantilly   Baked Raisin Custard   Sherbet
Vanilla or Chocolate Ice Cream   Royal Anne Cherries
Chantelle Cheese and Crackers

Assorted Bread and Rolls

Coffee   Tea   Iced Tea   Milk   Chocolate Milk

Fig. 1. A typical dinner menu.
Note the place occupied by horticultural products.

HORTICULTURE'S OTHER CONTRIBUTIONS

Horticulture, however, is not concerned exclusively with the production of food plants. Great numbers of plants are grown for their ornamental value, and their selection, breeding, propagation, planting, arrangement, and care fall within the horticultural field. The importance of this phase or branch of horticulture cannot be measured by acreage or space involved, but depends more on the satisfaction that people get from arranging and tending plants and from seeing them and the effects that they produce. Something of the aesthetic value that may be realized from the skillful use of even a single plant is illustrated in Figure 2. As any country becomes older and more particularly as its people come to have

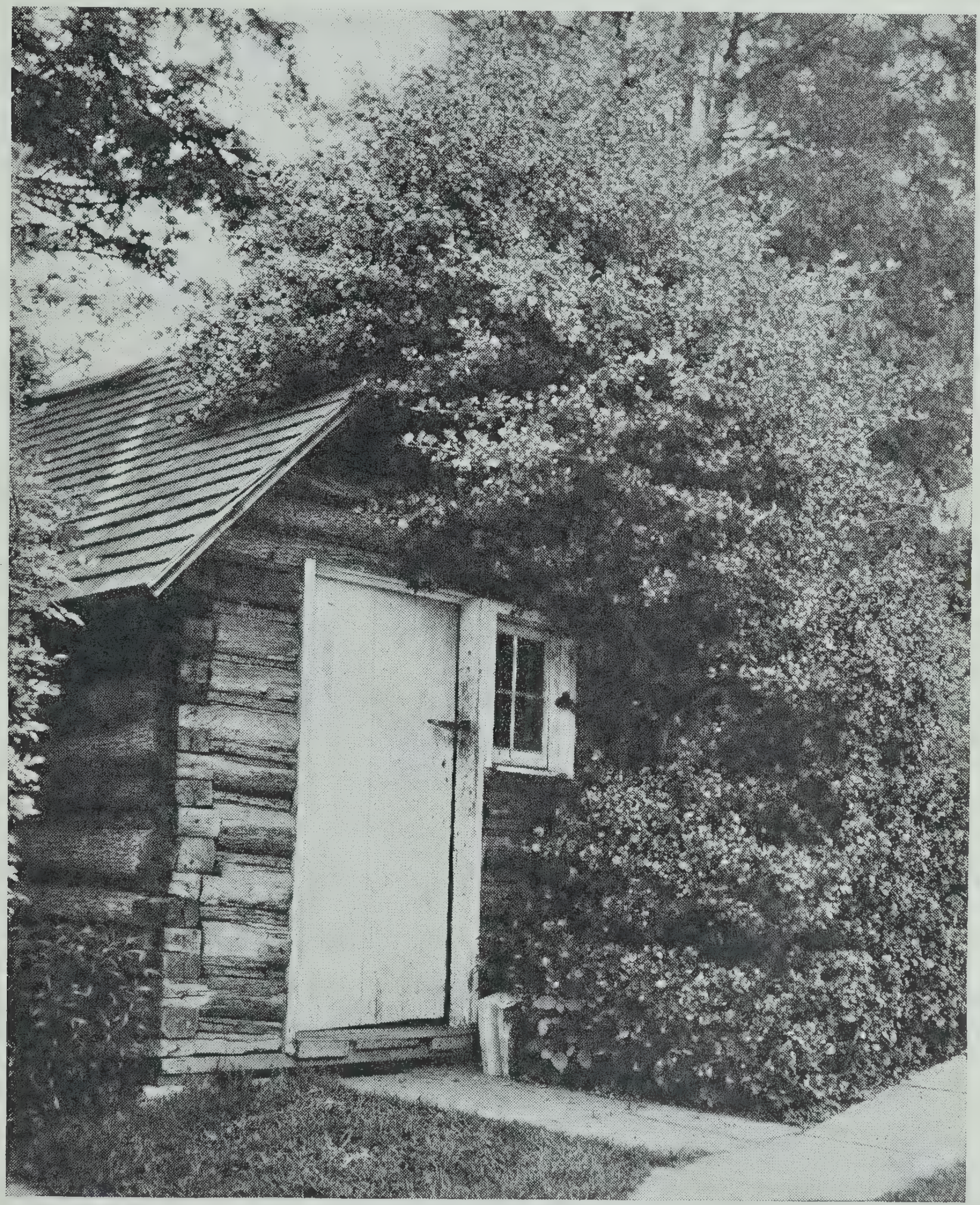

FIG. 2. Just a tool shed, but a single vine of winter creeper (*Euonomus radicans vegetus*), planted at one corner that has climbed to its ridge and spread over and hidden a part of its gable end, has made the combination an attractive feature of the landscape.

both the time and the means for more leisurely living, ornamental horticulture, along with travel, reading, and the various arts, comes to occupy an increasingly important place in their interests and activities. This is in contrast to all other branches of agriculture, for people will eat and wear only about so much; indeed, as hours of labor decrease and with better and more comfortable housing, there is a tendency both to eat and to wear less.

THE WORK OF THE HORTICULTURIST CLASSIFIED

The inference that would be gained from the attempt that has been made more or less to define or delimit the field is that, like operating a lathe or driving a truck or selling shoes or baking bread, horticulture is just another occupation, a means of making a living. Such indeed is all that it is for many people. On the other hand, the management of an orchard or other production enterprise that represents an investment of tens of thousands of dollars, a labor requirement of perhaps thousands of man-days concentrated within a few weeks, the efficient use of materials, machinery, and equipment, is comparable to the operation of a factory and classifies as a business. Furthermore, just as many enterprises represent the application of the sciences of physics and chemistry to the problems of the engineer or manufacturer, so the horticultural enterprise amounts essentially to the application of biochemistry, plant physiology, and genetics to the breeding and culture of oranges, onions, or orchids. Indeed it is only to the extent that he is acquainted with these sciences that the horticulturist can understand the principles underlying the culture of his crops. If he would effectively control insects and diseases, he must be something of an entomologist and pathologist and have some knowledge of the chemical and physical properties and reactions of insecticides, fungicides, spreaders, stickers, and other materials in his arsenal of defense. If he would avoid tipburn of leaves, russeting of fruits, scalding of bark, and blasting of flowers, he must know much about the ways in which temperature, moisture, nutrients, and light influence various plant structures and functions. If he would have a smoothly operating enterprise, he must be something of a psychologist and director of personnel in order to obtain the maximum amount of service from a given amount of labor with the minimum of friction. If he is to receive a proper return for his products, he must not only be a good sales-man but have a wide acquaintance with market outlets, market trends, and transportation methods. He must make the business pay.

Besides being an occupation, a business, and a science, horticulture is an art. It is one thing to know how to compost soil for a greenhouse bench, when and how to plant roses in it, the night and day temperatures at which they should be maintained, to be able to recognize mildew, aphids, chlorosis, and black spot and know what to do for them; it is something else to be able to produce in a single forcing season fifteen to twenty large, well-formed flowers per plant with long stems and perfect foliage. It is one thing to be able to make ordinary apple "cider"; it is quite another so to blend, clarify, and pasteurize the product of a half-dozen varieties that an "apple juice" is produced that critics and consumers generally recognize as a real competitor of the best brands of other fruit juices for cocktail and beverage purposes. To be a producer of a product of the first type calls for much knowledge and often considerable careful work; to be a producer of a product of the second type demands all that and something more in the way of real skill and fine craftsmanship.

Last but not least, proper utilization of ornamental plants calls for true artistic ability. Indeed landscape gardening is generally classified along with the fine arts. Flower arrangement similarly calls for an application of the same principles underlying combinations of form, texture, and color that are employed by the painter. Obviously many, if not the majority, of those who grow plants for ornament — and this, incidentally, includes a large percentage of the population — possess limited artistic ability and skill in design and arrangement. Nevertheless, as these people come to effect real achievement in this direction, they may have the satisfaction of knowing that they are developing the artistic side of their personalities just as truly as though they were to draw, paint, or play the violin.

PROBLEMS

1. Make an itemized list of all the things you eat on one average day; classify them (as cereals, meats, fats, fruits, vegetables, and so on); assign to each item and group its approximate retail value; determine the proportional volume and value of each class.

2. Using the last United States census data on agriculture or other available statistical data, construct tables showing acreages, quantities

produced, and estimated wholesale values of the several main *classes* of farm products produced (*a*) in the United States, (*b*) in your own state, (*c*) in your own county.

3. Using the last United States census data on agriculture and commerce or other available statistical data, construct tables showing approximate annual exports and imports of the several main *classes* of farm products.

4. Compare farmers' selling prices for several typical field-crop products (for example, wheat, corn, eggs, milk, pork) and several typical horticultural products (for example, apples, oranges, potatoes, tomatoes, head lettuce) as quoted for a given date in one of the produce trade journals, with retail-store prices for the same items (flour and corn meal in the case of wheat and corn), as listed in retail-store advertisements for the same date.

5. List (*a*) a group of horticultural products which requires no processing between producer and retailer, (*b*) a group which always requires processing (drying, canning, pickling, etc.), (*c*) a group which may or may not be processed. Assign approximate producer's and retailer's prices to each item, and estimate percentages of the consumer's dollar received by producer, processor, distributors, and transportation agencies in each instance and with each group.

6. List and compare the number of (*a*) plants grown for ornamental purposes in parks, along roadsides, in private grounds, or in homes that you recognize and know by name, with (*b*) the number of songs or musical numbers you recognize by ear and know by name, with (*c*) the number of plays and movies you have seen and recall by name, with (*d*) the books or serial stories you have read and of which you recall the title, with (*e*) the paintings and pieces of sculpture you have seen and whose titles and artists' names you remember.

CHAPTER II

CLASSIFICATIONS OF PLANTS

FROM time to time for purposes of convenience plants have been classified in various ways that make possible reference to a large number of kinds under a group name without enumerating or specifying each one individually. The bases of these groupings have varied according to the features of plant growth that have been under consideration at the time.

BOTANICAL CLASSIFICATIONS

The botanist, or more specifically, the *taxonomist* (taxonomy being that branch of a science which concerns itself with description, naming, and classification), classifies them according to their so-called *botanical* relationship, the supposed degree to which they trace back to a common ancestry as they have evolved into their present forms. He divides the plant kingdom into divisions, orders, families, genera, and species. Plants that are essentially alike when grown under similar conditions, that interbreed freely, and that are more or less distinct from other kinds with which they do not freely interbreed, are placed together in one *species*. Other plants rather closely related to these, that freely interbreed among themselves, but are more or less obviously distinct forms and do not freely interbreed with the first group are placed in a different species. These two species would be placed in the same *genus* unless the two groups are markedly different, in which case the two species would be in different genera. Thus, all the eastern black walnuts are placed in one species (*Juglans nigra*), the butternuts in another species (*J. cinerea*), the northern California walnut in another (*J. hindsii*), the Texan walnut in still another (*J. rupestris*), and finally the English or Persian walnut in another (*J. regia*). These several species are readily distinguished from each other in tree, flower, and nut; they do not interbreed freely even when growing side by side, and the occasional hybrids that are formed between them are more or less sterile. They all have certain common characteristics, however, and are placed together in a single large group or genus (*Juglans*). Some other plants which resemble these less closely may be placed in a different genus, though perhaps in the same family. Thus, the hickories constitute a group or genus (*Hicoria* or *Carya*) more or less comparable to the walnuts, and both genera, along with a number of others are classified in one family (the Walnut family or *Juglandaceae*).

The generic and specific names of any single species of plant form the basis of the so-called *binomial* system of nomenclature and together constitute the "botanical" or "scientific" name by which it is known. Most of the botanical names of species are Latinized in form (for example, *Fragaria chiloensis*, the Chilean strawberry), and in many instances the specific name is to some degree descriptive. In writing this name the generic term is always capitalized; the specific name is not capitalized. When plant groups or forms that appear to be quite distinct interbreed freely and produce fertile offspring that in turn interbreed freely with each other and with their parent forms, the taxonomist classifies them as different *races* or *subspecies*. Thus, cabbage, cauliflower, broccoli, kale, Brussels sprouts, and kohlrabi are classified simply as subspecies of a single species (*Brassica oleracea*) because they intercross freely and maintain their identities only when crossing is prevented and their lines of descent are kept separate. There are, however, many exceptions to this definition or concept of the species. This is well illustrated in such groups as the plum and grape. There are literally scores of species of *Prunus* and *Vitis;* hybridization takes place freely, and many of the hybrids are fertile. Indeed, some of the hybrid races that have been developed have more varieties and are of greater commercial importance than either or both of the parent forms. In some groups, such as the roses (*Rosa*) and dewberries (*Rubus*), recognition of distinct species is very difficult because of intergrading, and presumably hybrid, forms. Such groups are said by the taxonomist to be *polymorphic*, meaning "of many forms."

The main basis of the taxonomist's classification of plants is flower structure, sometimes rather small differences serving to differentiate between groups. Thus, the occurrence of plant parts (for example, sepals, petals, carpels) in threes or multiples thereof, or in fives or multiples thereof, at once classifies a plant in one or another of two large groups, each of which includes many families, scores of genera, and thousands of species. Among the pome fruits the partial coherence of the styles or their complete separation to the base distinguishes the apples from the pears. Many other features of the plant — its growing habit; its stem structure; its leaf size, shape, and veination; the kind of fruit and seed it produces — are likewise used to assist in its proper classification.

Knowledge of the botanical or taxonomic classification of plants is very useful to the horticulturist because it serves: (1) to identify and name them; (2) to afford at least some idea of the closeness of their relationship, that is, lines of descent, to other kinds; (3) to suggest with what other kinds they possibly may or may not be interbred or crossed; (4) in some instances to suggest the kinds with which they possibly may be intergrafted — intergrafting usually being limited to closely related kinds but often to kinds somewhat more distantly related than those with which interbreeding is possible; and (5) often to suggest certain soil and cultural requirements, climatic adaptations, and the kinds of insects and diseases to which they are subject. As an illustration of this latter point, attention may be called to the common soil, fertilizer, and tillage requirements of cabbage, cauliflower, Brussels sprouts, and the other so-called "cole" crops, all of which belong to the species *Brassica oleracea*, and to their common susceptibility to the same species of cabbage "worm," aphis, club-root organism, and so on. Even the apple, pear, and quince, belonging to different genera, are troubled by essentially the same pests, and the producer, knowing of their taxonomic relationship, can be reasonably certain that control measures for pests of the one are likely to apply to those of the other. On the other hand, botanical relationship is not an invariable index to growing habits and cultural requirements. Spanish moss (*Tillandsia usneoides*), an air plant, and the common pineapple (*Ananas sativus*), a land plant, belong to the same family (*Bromeliaceae*), but are about as unlike in appearance and culture as two plants could be; the velvety creeping bent (*Agrostis capillaris*) of the golf course "greens" and the giant bamboo (*Phyllostachys bambusoides*) of the tropics that grows to a height of seventy-five to one hundred feet are both true grasses; and the high-bush and low-bush blueberries (*Vaccinium corymbosum* and *V. pennsylvanicum*), though so closely related that they are readily hybridized, call for entirely different cultural conditions, the one being a bog and the other a dry-land, almost xerophytic, plant.

Another group of botanists, the *ecologists*, classifies plants according to the associations in which they are found growing naturally, for example, desert, prairie, bog, aquatic, and deciduous rain forest. This classification overlaps, or perhaps more accurately cuts across, that of the taxonomist, for in a single habitat, as a desert, a dune, or bog, may be found plants belonging to many different species, genera, and even families and orders. Thus, side by side in the desert may be found the shrubby mesquite (*Prosopis juliflora*), wire grass (*Aristida purpurea*), sage brush (*Artemisia tridentata*), and numerous bulbous plants and cacti, each one capable of surviving periods of extreme drought. A dune association may include beach grass, wild grape, and bird cherry. Knowledge of the ecologist's classification of the plants he is growing is just as useful, often more useful, to the horticulturist as is information to the effect that they belong to certain families, genera, and species. If it is a bog variety of blueberry, he will know that it must be cultivated in a moist soil with a high water table; if it is a low-bush form descended from the sandy-plains type, he will know that its practical culture is limited to high, dry land. If he is making a rock garden in a sunny exposed situation, he will know that he should depend largely on bulbous plants, aloes, cacti, euphorbias, sedums, and other desert groups. If he wishes to grow orchids, he will know that to be successful he should provide the conditions of the tropical rain forest.

AGRICULTURAL CLASSIFICATIONS OF PLANTS

Agriculture, too, has its classification of plants, and since agriculture grows them for utilitarian purposes, it might be expected that its classification is based on the uses to which they or their products are devoted. Thus, the farmer finds it convenient to speak of such groups as timber, forage, grain or cereal, fruit, vegetable, fiber, drug or medicinal, and ornamental plants. Forestry concerns itself with timber crops; general farming and stock-raising concern themselves with forage, fiber, and grain crops; plants grown as vegetables, for their fruits, for medicinal purposes, for the making of spices and condiments, for the preparation of beverages (coffee, tea, cocoa, wine, etc.), or as ornamentals belong in the field of horticulture. The number included in this field is very much greater than in the other agricultural fields, though as already stated, the acreage devoted to their culture and the value of the crops produced are much less.

HORTICULTURAL CLASSIFICATIONS OF PLANTS

Though the grouping of horticultural crops or plants as fruits, vegetables, drug plants, and ornamentals is itself a simple classification, the horticulturist finds it useful to supplement this with another that is somewhat more detailed. This is based on the general growth characteristics of the plants, growth characteristics that determine in large measure their cultural requirements. The main subdivisions of this classification are as follows:

1. ANNUALS

As the name indicates, annuals are plants that live one year or less; that is, the plant makes its vegetative growth, flowers, and produces seed within one year of the time seed is sown, and then the plant dies. With some plants, for example, certain varieties of cotton, nearly a whole year is required to complete the life cycle from seed to seed, even in tropical or subtropical sections where conditions are continuously favorable for growth; with others, for example, tobacco, half a year or less is necessary; with still others, for example, certain varieties of garden cress, beans, peas, and many weeds and ornamentals, only two or three months are required for the completion of the life cycle. Under favorable conditions the seed of some of the early varieties of the garden pea and of the diamond flower (*Ionopsidium acaule*) germinates, grows, flowers, produces seeds, and dies down in sixty to seventy-five days. These are all classified as annuals. Sometimes the terms *long season* and *short season* are used to distinguish between those that live only a few months and those that survive for six months to a year. Also generally classified as annuals are many herbaceous plants with an indeterminate life period. Though commonly grown as annuals, under suitable conditions they may remain alive and continue to grow more or less indefinitely, in the meantime producing a succession of flowers, fruits, and seeds. Here belong the tomato, eggplant, snapdragon, and many other commonly grown vegetables and ornamentals. Plants of this type are sometimes spoken of as *plurannuals*. Also classified here are such plants as *Coleus* and *Pelargonium*. If grown outdoors in temperate climates, they are killed by frost in the fall and must be started from seeds the next spring, or cuttings may be taken before they are frozen and carried through the winter in a greenhouse for planting outdoors in the spring. On the other hand, if they are grown outdoors in a frost-free climate, or if they are grown the year around in the greenhouse, they become perennials. It is thus seen that the term *annual* is flexible, and hard and fast lines cannot be drawn between it and other groups.

II. BIENNIALS

Biennial plants ordinarily require two years, or at least parts of two growing seasons with more or less of a dormant or resting season between, to complete their life history. Seed is sown in spring or summer, and vegetative growth only is made that year. The following spring and summer the plant produces flowers, fruits, and seeds (usually with a very limited amount of new vegetative growth) and then dies down. The onion, beet, carrot, celery, cabbage, and Canterbury bell (*Campanula medium*) are good examples of biennial plants. When many of these biennials, for example, the beet and carrot, are grown as crop plants, they are in reality cultivated as annuals, since it is their first-year roots (or other plant organs) stored with food that are desired. Only when raised for their seed are they grown as biennials. Furthermore, many plants that normally grow as biennials can be made to produce flowers, fruits, and seeds their first growing season, and thus in reality be converted into annuals, by special cultural treatment. Thus, if young celery plants are checked in their growth, especially by low temperature, when only a few weeks old and a few inches high, they are likely to "bolt," that is, produce flowers and seed and then die down, before the end of the season. Conversely, many normally annual plants can be converted into biennials by starting them in mid or late summer or early fall so that there is not enough time for them to complete their growth before cold weather sets in. Their growth is arrested; they go through the winter in much the same condition as a biennial and then flower and produce seed the following summer. The "fall" spinach crop of most sections and the popular forget-me-not (*Myosotis scorpioides*) are biennials as are the carrot and beet as they are commonly grown, and the "winter" and "early spring" spinach crop of the central and southern states is even more truly grown as a biennial. Wheat is seldom thought of as a biennial plant, but the "winter" wheat crop is grown as a more or less typical biennial.

The term *biennial*, no less than *annual*, is flexible, and hard and fast lines cannot be drawn between it and some of the other groups.

III. PERENNIALS

Any plant that normally lives, or would live if it had the chance, for more than two years is a *perennial*. There are two main groups of perennials — *herbaceous* and *woody*.

A. Herbaceous Perennials. Herbaceous perennials are those with more or less soft, succulent stems. In temperate climates the tops die after a season of vegetative growth, sometimes dying down because of drought, sometimes killed by frost or freezing, sometimes dying simply as an after effect of flowering, fruiting, and producing seed. Their crowns, however, and often their roots, remain alive and produce new stems and tops another season upon the appearance of conditions favorable for growth. In other words, their tops are annual, though their below-ground parts are perennial. Asparagus, rhubarb, Oriental poppy (*Papaver orientale*), bleeding heart (*Dicentra spectabilis*), and many varieties of *Phlox* are typical of this class. In tropic and subtropic climates the tops of herbaceous perennials may likewise die down, due to natural causes leading to a period of rest following flowering and seeding, or they may remain alive for long periods.

Most of the so-called *bulbous* plants, using that term in its broader sense, are to be classed as herbaceous perennials. They differ from other herbaceous perennials principally in the fact that they possess more or less fleshy underground food storage organs — either roots or stems or one of their many modifications. Their stems and other above-ground parts usually have a rather short period of active vegetative growth, alternating with a long resting period.

Biennials and herbaceous perennials enter the dormant season stocked with a supply of food out of which a large amount of new growth can be made quickly the following season, when environmental conditions are again favorable. This is in contrast to the annuals which must develop from seeds and manufacture their own food supplies as the season advances. Consequently, it is the biennials such as parsnips and salsify and perennials such as rhubarb and asparagus that furnish us our earliest spring vegetables, and among the ornamentals it is biennials such as Canterbury bell (*Campanula medium*) and perennials such as the tulip, phlox (*Phlox subulata*), and iris that provide the early flowers. Annuals are depended on more for midsummer and fall flowers, though some of the short-season kinds flower earlier than some of the biennials and perennials.

There is no certain way of telling from its appearance as a young seedling whether a plant is an annual, biennial, or herbaceous perennial. Neither can the several groups be distinguished from each other in midseason when the plants have attained full size or perhaps are in flower, though somewhat earlier in the season of their second (or in the case of perennials, still later) years the biennials and perennials will be larger than the annuals because they have grown more rapidly with the supplies of foods stored in their roots, crowns, or other underground structures. Following flowering and seed production the annual plant dies, its root as well as its stem. The tops of the one-year-old biennial and of the perennial may remain alive, in a mild climate, or they may die down, in a more severe climate. In both cases, the below-ground parts remain alive. Consequently, in the fall, at least in northern sections and also in the South in the case of many plants, annuals can be distinguished from biennials and perennials, but the latter two groups cannot be distinguished if the biennial is only a year old. If it is two years old, it can be distinguished from the perennial but not from the annual.

B. Woody Perennials. Though the stems of many herbaceous perennials, and likewise of many annuals and biennials, become somewhat woody and those of many woody perennials are rather soft, there is seldom any great difficulty in distinguishing between them. The difference, however, is in hardness, in toughness of woody fiber, rather than in the size or age that the plants attain. In the case of trees, shrubs, or vines that survive for a number of years there is never any question as to how they should be classified. Some plants, however, growing as woody perennials in their normal habitat, take on the characteristics of herbaceous perennials when grown where their tops freeze to the ground in the winter but where the temperature is not low enough to destroy their roots. Thus, the fig and *Buddleia davidi* are woody perennials in tropic, subtropic, and mildly temperate zones. In southern

Michigan, if well mulched each fall so that their roots do not winterkill, they grow as does asparagus or the peony. Many species and varieties of blackberry and dewberry are perennial plants with *woody biennial* canes; others, as the Himalaya and Evergreen, have *woody perennial* canes. Both types are classed as woody perennials. Still other kinds, however, have annual canes, or more accurately, annual *shoots* — no bramble growth being called a *cane* until in its second year. If the shoot never becomes very woody, the species or variety is more properly classified as an herbaceous than as a woody perennial. Thus again, the division line is arbitrary and subject to change.

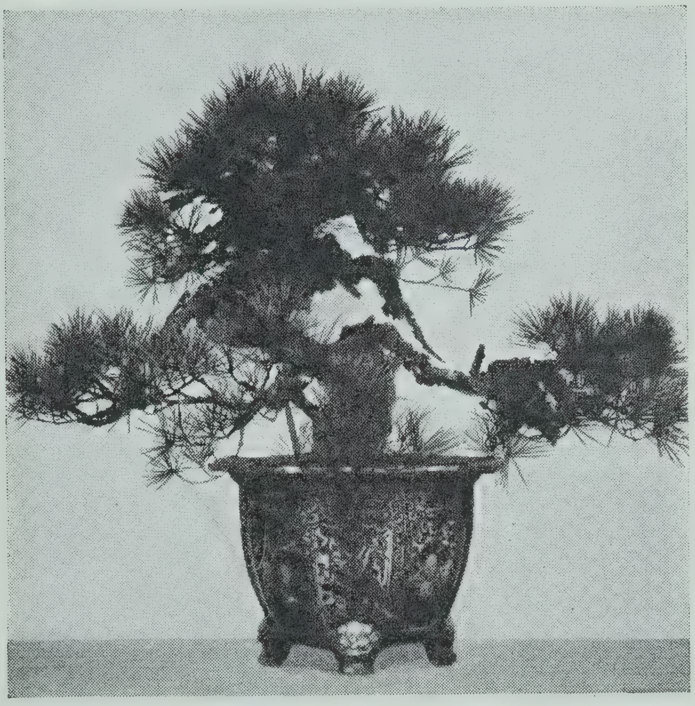

FIG. 3. A 250-year old tree of the Japanese table pine (*Pinus densiflora*). The tree itself was twenty-four inches high and had a spread of thirty-eight inches at the time the photograph was made in August, 1941. The pot in which it was growing had a diameter of thirteen inches at the top and nine inches near the bottom. Dwarfing was accomplished by cultural means. Courtesy of Dr. Y. Asami, University of Tokyo.

Trees, Shrubs, and Vines. Woody perennials are classified as trees, shrubs, or vines, according to their habit of growth. Typically trees are upright in habit, and their stems or trunks, which usually take the form of a central axis, are the dominant part of their framework. On the other hand, shrubs typically have no main trunk or central axis but a number of erect or semierect stems or axes springing from the region of the crown, no one of which is likely to outgrow the other for any considerable period and become a dominating feature in the framework of the plant. Though, in general, trees attain a larger size than shrubs, the basic difference between trees and shrubs is in form, not in size. The young tree only a few feet or even a few inches in height is nevertheless a tree because it has a tree's habit of growth, even though it may be overtopped many times by shrubs that surround it. Some trees, for example, the Japanese table pine (*Pinus densiflora*) that at 250 years of age may be less than two feet in height (see Figure 3), usually never acquire the stature attained by many shrubs, for example, some of the bamboos (*Dendrocalamus*) that at ten years of age may have culms that are upwards of fifty feet tall. One of the dwarf varieties of the Norway spruce (*Picea excelsa pygmaea*) grows to a height of only four or five inches, but nevertheless is a tree. Many trees may be artificially trained to grow as shrubs, a condition frequently found in hedges of Osage orange (*Maclura pomifera*) or Norway spruce (*P. excelsa*). Similarly many plants

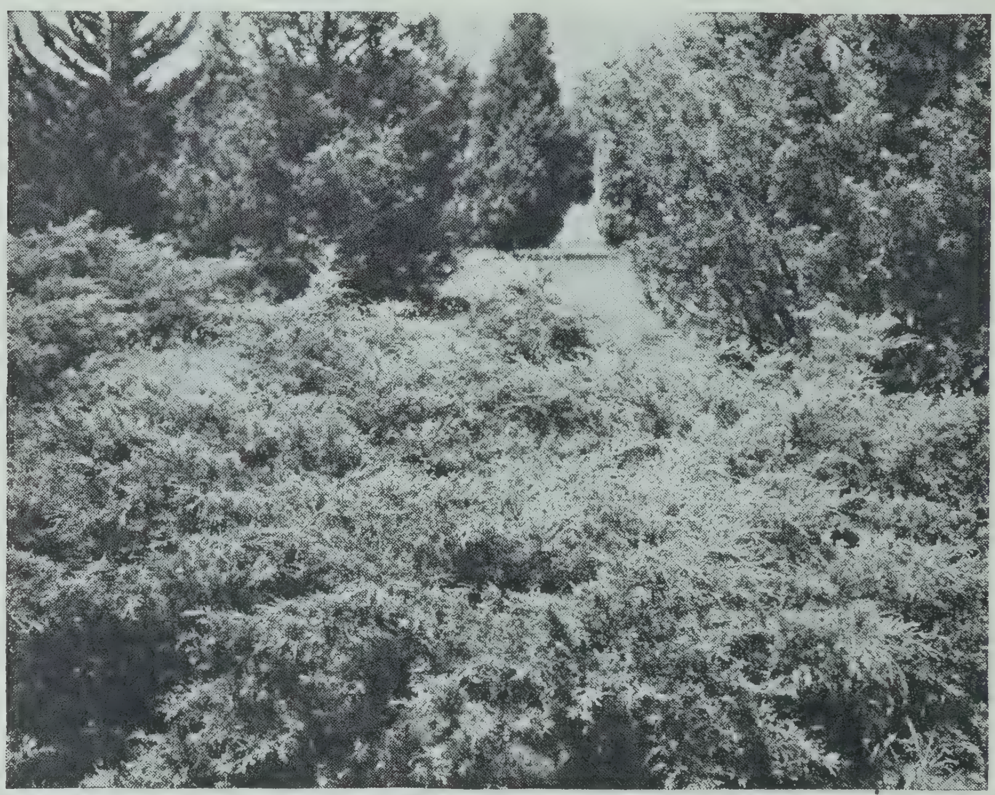

Fig. 4. In the lower foreground a shrubby-growing form of Pfitzer's juniper (*Juniperus chinensis pfitzeriana*). It has a spread of about twelve feet and a height of less than three. It is of about the same age as the tree form of the same variety shown in Figure 5.

that naturally grow as shrubs may by training be made to assume a tree form, illustrated by the Pfitzer's junipers shown in Figures 4 and 5. Tree lilacs, tree gooseberries, tree roses are common examples. Plants that naturally assume a form more or less intermediate between trees and shrubs are often described as being treelike or *arborescent* shrubs, or shrublike or *frutescent* trees.

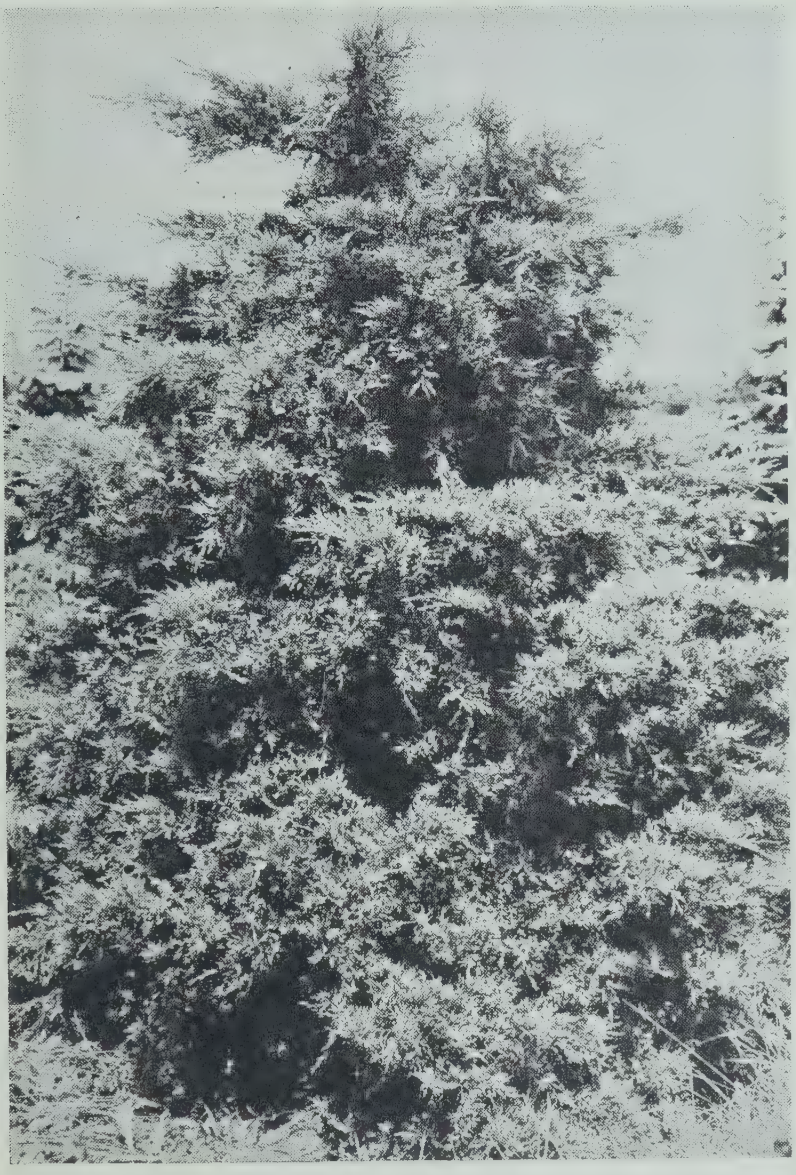

Fig. 5. An arborescent form of Pfitzer's juniper (*Juniperus chinensis pfitzeriana*). It has a spread of about six feet and a height of about nine. It is of about the same age as the shrubby form of the same variety shown in Figure 4.

Vines, both woody and herbaceous, are characterized by stems that are too slender and flexible to support their branches and leaves in an erect position. Consequently, they spread over the ground or climb over trees or shrubs or inanimate objects that serve for their mechanical support. There is, however, no clear sharp line between trees and shrubs on the one hand and vines on the other. There are many intermediate forms. Some of these forms are characteristically intermediate in habit of growth throughout their lives. Others, for example, the common English ivy (*Hedera helix*), grow as vines while young and then as they become older may acquire more or less of an arborescent habit. Cuttings taken from the juvenile forms produce plants that from the first grow as typical vines; cuttings taken from the mature arborescent forms usually produce plants that either are shrubby or intermediate in character. Still others, as the *Euonomus radicans vegetus* shown in Figures 6 and 7 grow as shrubs or as vines depending on their location and environment and cultural treatment.

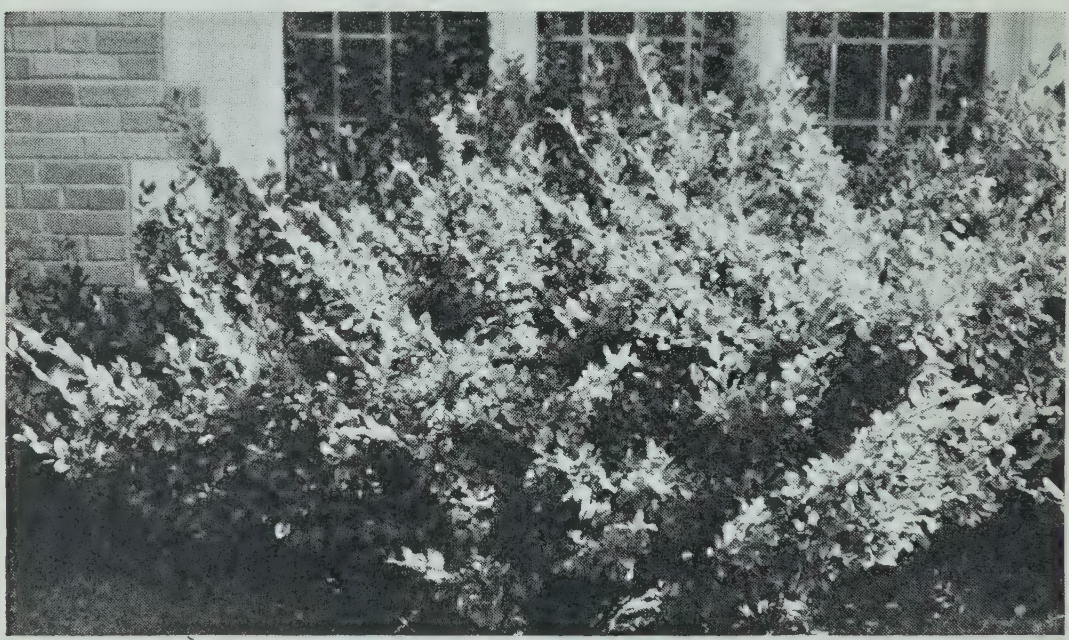

FIG. 6. *Euonomus radicans vegetus* used in a foundation planting but set far enough away from the building so that it grows as a low spreading shrub. Compare with the climbing form of the same variety shown in Figure 7.

FRUITS, VEGETABLES, AND ORNAMENTALS DISTINGUISHED

Mention has been made of the fact that horticulture is concerned with fruits, vegetables, ornamentals, and medicinal plants and that this grouping as to uses constitutes a classification — perhaps the most used classification of any. In general, when the fruits of a plant are used for food it is classified as a fruit, and when other structures, for example, leaves or roots, are used for food, it is classified as a vegetable. There are, however, some exceptions sanctioned by usage. Thus, in the United States the tomato is classified as a vegetable crop, though it is its fruit that is used. The same statement applies to the cucumber, the eggplant, pepper, vegetable marrow, and many others. In Europe these plants are considered as fruit crops.

Many plants are cultivated for their ornamental value exclusively. In such instances there can be no question as to how they should be classified. Many others, as the grape, are grown both for their ornamental value and for the food products that they yield. Such plants are as appropriately classified in the one group as in the other. Similarly some plants, as pyrethrum (*Chrysanthemum cinerariaefolium*), are grown as ornamentals and for medicinal or insecticidal products made from them and are classified in the one group or the other, depending on conditions.

Subdivisions of these main groups of horticultural plants are likewise made for convenience. Thus, among the vegetables we have the root crops, the cole crops, the cucurbits, and so on; among the fruits we have the pomes, the stone fruits, the berries, the citrus group; among the ornamentals, we have the succulents, the dwarf evergreens, the alpines, stove plants, hedge plants, plants for shaded locations, and many others.

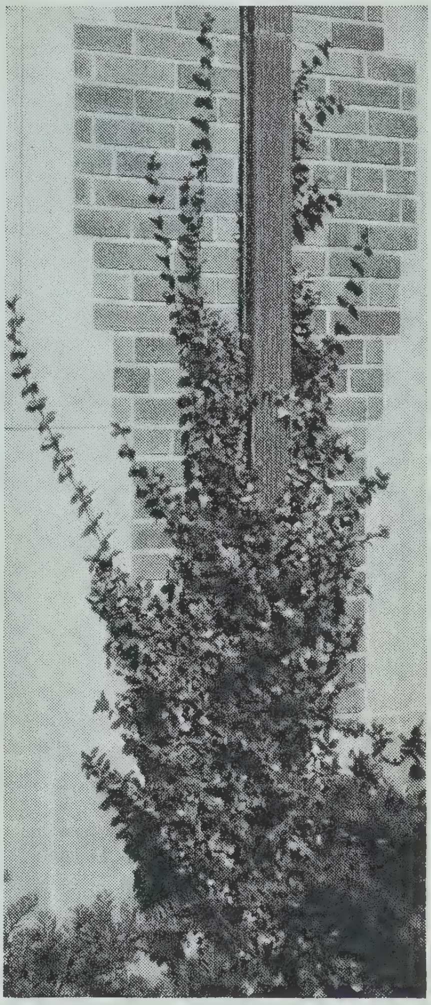

FIG. 7. *Euonomus radicans vegetus* set close to a building that is growing naturally as a vine. Compare with the shrubby form of the same variety shown in Figure 6.

SEMINALLY AND VEGETATIVELY PROPAGATED PLANTS

The fiber, cereal, and forage plants of the agronomist are seed-propagated. So, too, are practically all of the annual and biennial vegetables and ornamentals. On the other hand, most horticultural perennials, both herbaceous and woody, are propagated vegetatively, that is, by means of cuttings, buds, and grafts. This is not because most of them do not produce seeds, but because the plants grown from their seeds are often not at all like their parents.

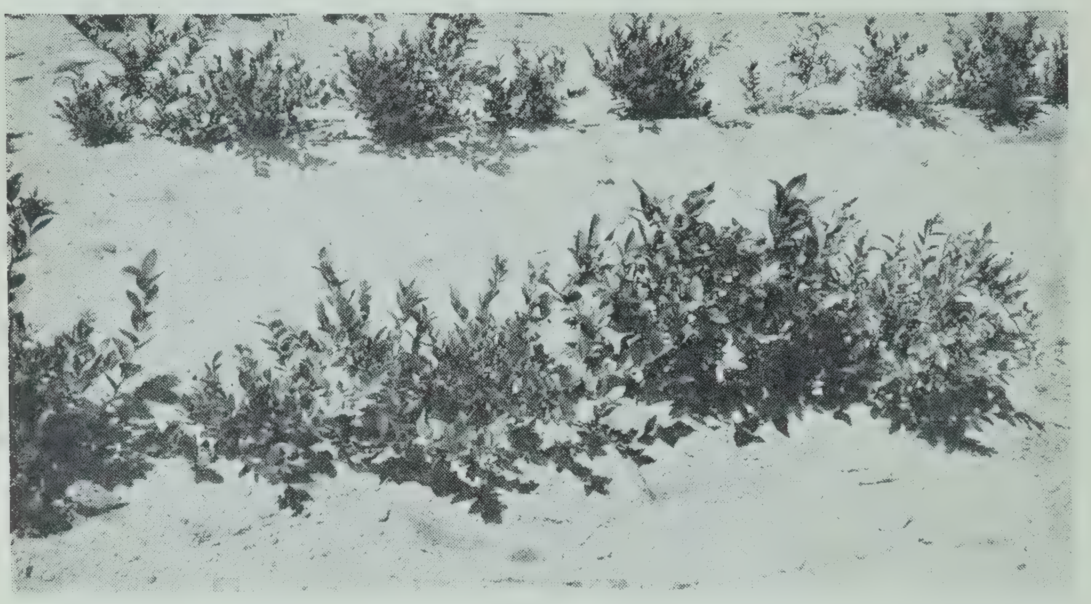

Fig. 8. Seedlings of the high-bush blueberry (*Vaccinium corymbosum*), four years old. Note their variability in size and habit of growth, as compared with the uniformity of cutting-grown plants of a single variety shown in Figure 9.

In other words, these plants do not "breed true" or "propagate true" when raised from seeds, a fact due to their mixed ancestry in contrast to the uniform — line-bred — ancestry behind the annuals and biennials. Plants grown from cuttings, buds, or grafts, being literally "chips off the old block," theoretically are exactly like their parents and in reality are usually so much like them that they cannot be distinguished from them or from each other. Thus, all Baldwin apple trees, Pineapple orange trees, and Caroline Testout rose bushes are exactly alike, because propagated vegetatively. A planting raised from seeds of these same varieties of apples, oranges, or roses (see Figures 8 and 9) shows a great diversity in size of plant, habit of growth, and general appearance. Another reason for propagating many perennials vegetatively is that it is much quicker and less expensive than by seeds. It takes ten years to raise plants of certain varieties of orchids to flowering size from seeds, only three years from cuttings. Strawberries require two years from seed to fruit and three years from seed to a full-sized fruiting plant, but a single season when grown from a runner. Some perennials never produce seeds, for example, seedless varieties of bananas and pineapples; some never even flower, for example, horse-radish and the Madame Salleron *Pelargonium*. Obviously, these plants must be propagated vegetatively.

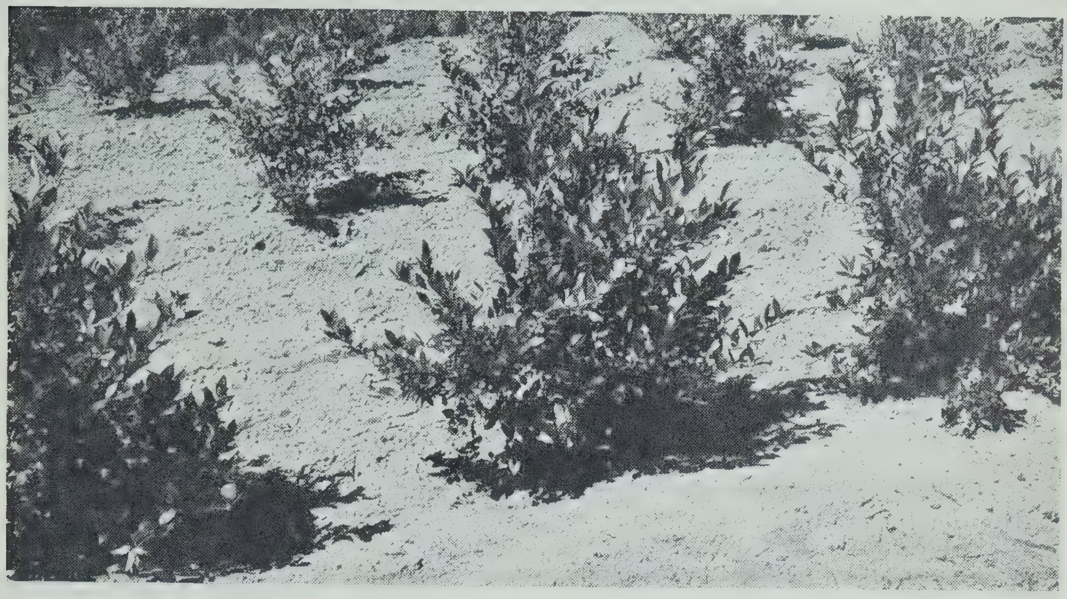

Fig. 9. Cutting-grown plants of the Rubel variety of the high-bush blueberry (*Vaccinium corymbosum*), four years old. Compare their size and uniformity with that of seed-propagated plants shown in Figure 8.

PROBLEMS

1. Make a list of the plants in your neighborhood that are grown both for ornamental and for some "utilitarian" purpose.

2. In Florida spinach is seeded in late fall, grows during the winter, flowers and produces seed in the early spring; in Virginia it is seeded in late summer, grows in the fall and early spring, flowers and produces seed in early summer; in Maine it is seeded in spring, grows in early summer, flowers and produces seed in late summer. How do you classify it — as an annual or biennial? Why?

3. Geraniums and pelargoniums are tender, soft-stemmed ornamentals, commonly grown as greenhouse or house plants or in flower beds in the summer. Frost destroys them. The Madame Salleron variety originated in France about 1860. It has never been known to produce seeds. Seldom does one find in a house or greenhouse a plant of this variety over a year old, very rarely one over two years old. It is constantly (usually annually) renewed from cuttings. Would you classify it as an annual, biennial, or perennial? Why?

4. In view of the way in which it has been explained in this chapter that celery, normally a biennial, is sometimes transformed into an annual, can you suggest a procedure for transforming an annual into a biennial?

A biennial into a perennial? An annual into a perennial? Upon what principle is this suggested transformation based?

5. For planting purposes the forester uses only seedling nursery stock, and the fruit grower uses principally vegetatively propagated nursery stock. How do you account for this difference?

6. We have seedless varieties of oranges and grapes, and they are highly valued. Seedless varieties of tomatoes and watermelons would in all probability likewise be highly valued, but we don't have them. Can you suggest some good reasons why?

7. From the standpoint of probable commercial value of the product, would it be more practicable to attempt to develop by breeding a seedless variety of strawberry or a seedless variety of walnut? Why?

CHAPTER III

PLANT STRUCTURE AND PLANT GROWTH

THE great diversity of plants — their extreme differences in size, shape, habit of growth, and every other feature — is perhaps their most obvious characteristic. Indeed it is so universal and so obvious that to the casual observer it passes unnoticed or at most is taken for granted. What could be more different in habit of growth than the oak tree and the ivy that climbs over it or the mistletoe that lives as a parasite upon it, more different in composition and structure than the watermelon and walnut, more extreme in respect to appearance and condition required for growth than the pineapple and the pine?

Nevertheless, some of these differences are more apparent than real. Closer examination and study of these same plants show that they have a number of things in common. They possess a structure that is basically the same, and they have parts or organs that are comparable from the standpoint of origin and early development; these in a general way perform the same functions. Thus, all the so-called *higher* or flowering plants consist of three main plant structures — root, stem, and leaf. The root system of the sugar beet may be so different in appearance from that of the sweet pea or tulip, the stem of the oak may be so different from that of the onion, and the leaf of the giant water lily of the Amazon (*Victoria regia*) may be so different from that of the garden asparagus that they seem to have nothing in common. Yet roots have the same basic structure (that is, they consist of the same kinds of tissues) and serve the same basic purpose of absorbing water and nutrient substances from the soil; the leaves, with a few exceptions, synthesize foods from raw materials derived from the soil and atmosphere. Even the vastly different stems serve the common purposes of transport of nutrients from roots to leaves and of foods from leaves to roots and of temporary storage in between. Furthermore, when the tissues that make up the various plant organs are examined under the microscope, they will be found to consist of cells that at least in their younger stages are very much alike, though perhaps differing considerably as they become older.

Recognition of these basic plant structures and of their various modifications, as exhibited by plants of different kinds and as influenced by different conditions, is a part of the necessary equipment of the plantsman and cultivator. Otherwise, structures that are entirely normal may be taken for excrescences due to insect or disease attack and mistakenly pruned away or needlessly treated. Conversely, outgrowths, malformations, and blemishes due to infections are not recognized and hence ignored, only to result in serious damage to or perhaps complete loss of the plant and crop.

THE CELL

As has just been stated, very young newly formed cells are more or less alike in their appearance, regardless of where they may be found. As seen in cross-section they are more or less rectangular in outline. Each cell consists of a very thin, membranous, elastic wall or sac, enclosing a living, semiliquid substance called *protoplasm*, which fills the cell almost completely (see Figure 10). This cell substance assumes different forms according to its position or function — as nucleus, cytoplasm, and plastids. The *nucleus* is a comparatively dense portion of the protoplasm, more or less spherical in shape and with a distinct outline; it may be near the center or to one side of the cell. Surrounding it is the *cytoplasm*, having a thick fluid or thin jellylike consistency; in the living cell it is in more or less constant movement, streaming back and forth within the cell wall. Embedded, suspended, or floating in the cytoplasm are *plastids* — small, dense bodies of various sizes, shapes, and colors. The plastids of cells of some tissues contain a green pigment, *chlorophyll*, that gives leaves their green color. The bright colors of many flowers, fruits, and leaves are due to pigments carried by the plastids of certain cells in their surface or subsurface tissues. In other tissues the plastids are packed with starch, in which case the whole plastid is spoken of as a starch grain. In young or actively growing cells these plastids are carried about within the cell by the streaming movement of the surrounding cytoplasm. In older cells and in storage tissues such as the tuber of the potato they do not move about freely. In every cell, as it grows older and larger, one or more "bubbles," known as *vacuoles*, appear in the cytoplasm; these are filled with water in which are dissolved various salts, food materials, pigments, and other substances derived from the soil or air or resulting from the physiological activities of the living parts of the protoplasm. In due course the small bubbles or vacuoles grow larger, coalesce, and eventually form a large central vacuole that occupies most of the cell. This forces the cytoplasm, which in the meantime has shrunken, with its embedded nucleus and plastids, against the cell wall where it forms a thin lining separating the wall from the vacuole.

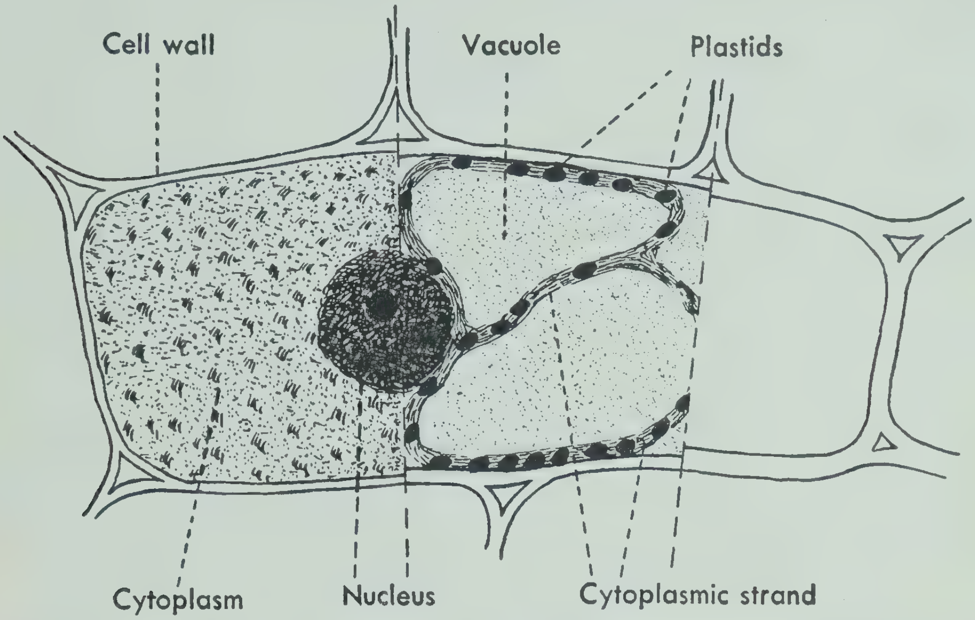

FIG. 10. Diagram of a single cell to show progressive development as it becomes older. The section at the left is very young and in a meristematic condition; note its nucleus, thin wall, and cytoplasm of more or less uniform consistency. The center section is somewhat older; its wall is thicker; the cytoplasm appears in the form of strands in which plastids are embedded, and much of the space is taken up by vacuoles which contain water with various substances in solution. The section at the right shows further differentiation; cell contents have largely disappeared, and the cell wall is much thickened.

CELL DIVISION

A plant cell, however, is something more than an object to be described as it changes in appearance from "youth to full stature." It is an object that lives and grows and, incident to living and growing, does certain things which should be narrated, if not explained. One of these is *division*. When a young cell reaches full size, any one of three things may happen: (*a*) It may divide; (*b*) it may become differentiated, that is, change in appearance and structure; or (*c*) it may become latent, continuing more or less indefinitely without appreciable change. Which one of these alternative courses it follows depends on its location and on conditions.

The process of cell division is too complicated for detailed explanation here. Suffice it to say that in that process the nucleus divides into two nuclei, and a wall is formed across the middle of the full-grown parent cell separating the two nuclei. This gives rise to two daughter cells that at first are each half as large as the parent but that qualitatively are just like it and therefore just like each other. Cell division ordinarily takes place only where and when growth is active; full-grown cells may remain without dividing or differentiating for considerable periods while conditions are unfavorable and then divide quickly when conditions change. The time required for the dividing process itself is usually very short, and if both internal and external conditions are favorable, a large number of divisions may take place, and correspondingly large numbers of new cells may be formed within a short period. Such cells that are full grown but essentially unchanged in shape or appearance, and likewise partially grown cells of the same type, are called *meristematic* cells.

INCREASE IN SIZE

Normally cell division is followed promptly by increase in size of the daughter cells, which soon attain the size of their parents and then themselves in turn divide. In reality, therefore, cell division and increase in size of cells in any one tissue or part of the plant take place concurrently. With an increase in the size of the individual cells, the tissue derived from them increases in bulk, the result being what we commonly recognize as growth. Whether this growth results in elongation or in radial extension depends upon in what plane the cell division takes place and the following orientation or arrangement of the daughter cells as a result of growth pressure.

In many instances, however, increase to full size does not immediately follow cell division. The daughter cells may grow to only a half or quarter of their mature size before dividing again, the result being many new partially grown cells whose further development may be delayed or arrested for a considerable period. Thus, in a young developing apple or tomato cell division is very active for a while; the quarter- or third-grown fruit contains nearly all the cells of the full-grown specimen; then days or weeks or even months after cell division has ceased, their growth in size is resumed or continued. This is well brought out in Figure 11.

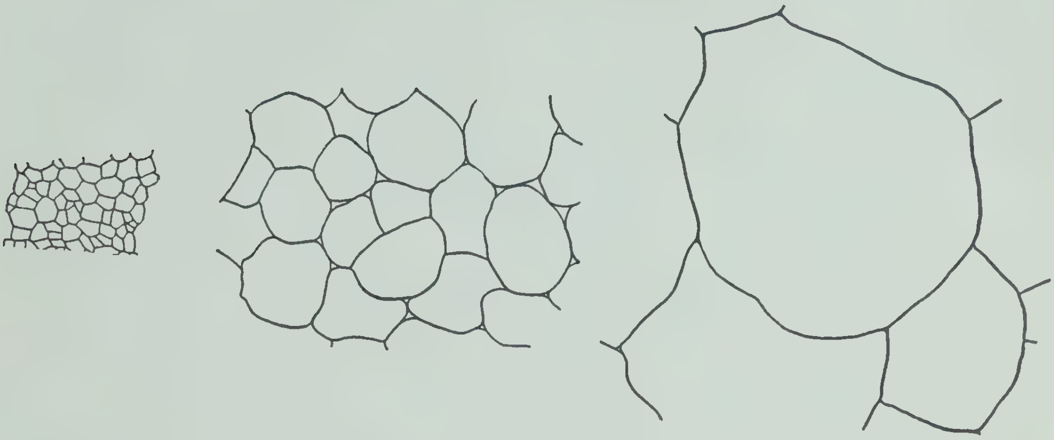

FIG. 11. Cells of the fleshy pericarp of the cherry as they appear at the: (left) full-bloom, (center) midseason, and (right) fruit-ripening stages. All subjected to the same magnification. Note their increase in size, as the season advanced, without much change in shape or in thickness of cell walls. Courtesy of H. B. Tukey, New York Agricultural Experiment Station.

DIFFERENTIATION

As cells become older, however, they may undergo change. Owing to pressure against soil surrounding the root or to other mechanical objects or simply to growth of and crowding by adjacent cells, they are squeezed or stretched into many diverse shapes. These will depend in considerable measure upon their location within the plant, well illustrated in Figure 12. This is *differentiation* in shape. Accompanying and following these changes in shape are others which result in thickening of the cell walls through the deposition of cell-wall substance on the inside, the net result being greater rigidity and, of course, a smaller content of protoplasm. This change, too, is *differentiation*, perhaps more extreme than that in shape. Figures 14 and 16 show both types of differentiation. Finally a stage is reached in the life of many cells when they come to consist largely of wall, and eventually the enclosed protoplasm disappears. This condition is illustrated in the pith cells of the catnip and corn stems shown in Figures 15 and 17. The enclosed cell cavity may then serve as a storage space for food materials, as in the grain of wheat, or a tube or pipe for the flow of sap, or the cell may serve only as part of the woody framework of the plant, supporting younger, more active parts.

Differentiation of cells from their original to their permanent form and structure, especially that which takes place beneath the outer layers of the bark, may involve little or no change in size or shape of the organ as a whole and therefore may not be visible unless the tissues involved are dissected out and exposed to view, and perhaps examined under a microscope. Nevertheless, what takes place is as truly a growth process as is cell division or increase in bulk.

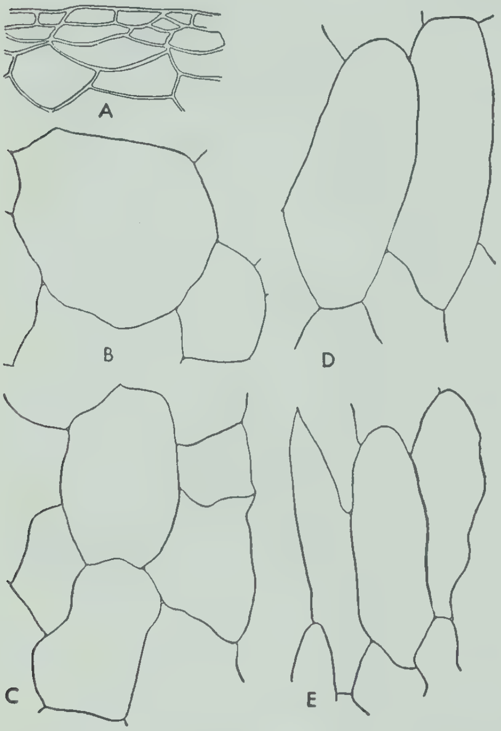

Fig. 12. Cell differentiation in the fruit of the cherry. A, epidermis or "skin," showing thickened walls and lateral stretching; B, flesh cells immediately beneath the epidermis; C and D, flesh cells progressively closer to the stone, slightly elongated because of stretching due to radial growth of the fruit; E, flesh cells close to the stone, much elongated because of greater stretching. Courtesy of H. B. Tukey, New York Agricultural Experiment Station.

The nature and degree of differentiation that takes place in the cells of plants as they become older depend both on the kind of plant and on the particular tissues involved. If the change in shape from that characterizing them in their young, undifferentiated meristematic condition is comparatively small, we call them *parenchyma* cells (see Figure 14). The term *parenchyma*, however, is broad and includes a great variety, for parenchymatous cells are found in many different parts of every plant, and different names are given to them, some of which are descriptive, some of which indicate where they are found or otherwise more or less serve to identify them. Thus, we find cork parenchyma in the bark, wood parenchyma in the rays of the wood, wound parenchyma or *callus* tissue at points of injury where healing is taking place. Parenchymatous cells in leaves and stems containing the green pigment chlorophyll are called *chlorenchyma.* Typical food-storage tissues, such as are found in the root of the beet, the tuber of the potato, the fruit of the apple and banana, the soft stems of cacti, the fleshy leaves and leaf stems of cabbage and celery, consist largely of parenchyma. More often than not the walls of parenchyma cells do not become greatly thickened, but in many instances as in wood parenchyma, they do eventually grow thicker.

In some instances cells that have changed from their typical meristematic condition enough to be classified as parenchyma, but which, nevertheless, have undergone comparatively little change, may revert to their meristematic condition, divide, and give rise to new daughter cells. This occurs regularly in the bark of many plants and is responsible for much of their continued formation of new layers of cork. It also often occurs where leaves, stems, fruits, or roots are injured, the resulting new cells aiding in the formation of protective wound coverings. When in the process of differentiation the cell becomes much elongated and its walls much thickened, the result may be a *fiber*. Fibers, like parenchyma cells, are extremely varied in size, shape, and appearance, depending on the kind of plant, the part of the plant where they are found, and the conditions under which they are formed. The cotton fiber is a very slender, very much elongated, thick-walled, tough but flexible, narrow-bored single cell. Single cells in the bast of the ramie plant (*Boehmeria nivea*) may grow to be a foot in length. The fibers of tough woods in general are comparatively long and thick walled; those of woods that break easily are generally shorter and not so tough, though they may have walls as thick or even thicker. On the other hand, some of the fiber cells in the root of a radish or the stem of a cactus or the fruit of a banana may be little thicker walled than their parenchyma cells and differ from them mainly in length. In general fiber cells serve principally to give mechanical strength to the tissues of which they form a part and constitute a substantial portion of the framework of the plant.

In the process of differentiation some cells, in addition to elongating, increase considerably in diameter; their lateral walls become thickened but, owing to their size, they have a comparatively large central cavity. With the contraction and subsequent death and absorption of their protoplasm they become essentially tubes, ducts, or vessels. Arranged end to end and with only thin end walls which in some instances become perforated, they serve admirably for the flow of water and the various materials that it carries in solution from one part of the plant to another. There is an almost endless variety of these tubular cells. Tissue composed principally of such ducts or vessels is called *vascular tissue;* distinct, cohering groups are called *vascular bundles* or strands. Some of these are shown in cross-section in Figure 17.

Many factors influence the length of time involved in the process of differentiation. Some cells in tissues of some species may complete all of their structural changes within a few weeks or even a few days; others may require years. Some individual cells may live only a few days or a few hours, after which they die and (1) are lost to the plant (as is true of root hairs) or (2) perhaps after dying or becoming physiologically inactive they become a part of the permanent woody structure of the plant that functions as a support for the living parts for years. Still other cells of certain long-lived plants may remain alive and physiologically active for many years.

Fully differentiated cells exhibit peculiarities of structure and appearance that often permit the identification of tissue of which they formed a part, the main functions that they served, and even the species of plant from which they came. Thus, a microscopic examination of grated horse-radish will reveal whether the product was made exclusively from the root of that plant or has been adulterated with white corn meal; microscopic examination of the filler for "hot dogs" will show whether they are made exclusively from animal tissue or consist in part of soybean meal; and ground cinnamon (*Cinnamomum zeylanicum*) can be distinguished from ground cassia bark (*Cinnamomum cassia*) by this same method.

Full-grown cells likewise vary greatly in size. Most of them are microscopic, being visible only with the aid of some magnification; on the other hand, some, for example, the cotton fiber, may be an inch or more in length. Even at that from 80 to 120 individual cells or fibers are twisted together at any one point in a No. 50 cotton thread. It is estimated that a cubic inch of ordinary cork contains upwards of a half-billion cork parenchyma cells.

CHEMICAL CHANGE

All differentiation of cells from their meristematic state or stage into the permanent units that they form in the structure of the plant involves more or less chemical change. The thickening of the cell wall is brought about by a change of some of the sugars in the cell sap to cellulose, which is a very closely related substance, and its deposition on the inside of the already existing wall of the cell — a kind of "plating out" of the cell substance, but accompanied by chemical change. Similarly, when a cork cell is formed in the outer bark of some plants, chemical change, though slightly different in this case, is effected. Thus, in the bark parenchyma cells of the cork oak (*Quercus suber*) five such layers are formed, two of which are waterproof, the thickness of all five layers being only about .0000886 of an inch. A comparatively simple chemical process is involved in the ripening of the full-sized apple, pear, or grape: Starch is changed into sugar. In the maturing ear of sweet corn the reverse is taking place: Sugar is being changed into starch. In none of these processes is there cell division or increase in size of cells, at least to any important degree. Yet they too represent differentiation and are all a part of the growth and development of the plants and plant parts in question.

PLANT TISSUES AND ORGANS

Through the division of a single cell, and a little later through the growth and division of the many subsequent daughter cells, we come to have a mass of cells more or less alike in their size, shape, and general appearance. This is *tissue* in its simplest form, *undifferentiated* tissue, such as is found in most parts of the partially developed embryo and endosperm of the seed, at the very tip of a growing stem or root or at any other place where new cells are being actively formed.

When all the cells of a mass of undifferentiated tissue undergo the same change in size, shape, composition, and appearance, we have a simple differentiated tissue, such as constitutes the pith of a stem or root, most of the pulp of an apple, the tuber of a potato, the edible portion of a cantaloupe, the corky portion of the bark. In the cases just cited the cells are parenchymatous, and consequently the resulting tissues are parenchymatous. When the differentiation is not uniform throughout the mass but takes one form at one point and a different form at another, a complex tissue results. Thus, in the rind of the watermelon, which is almost entirely parenchyma, we have larger, coarser, thin-walled cells bordering the central edible portion and smaller, more compact, thicker-walled cells toward the outside, with still thicker-walled cells constituting the epidermal and subepidermal layer. In the endosperm of the corn kernel we have both starchy and horny portions. In a crisp radish root at the right stage for eating, most of which consists of parenchyma, its cells are very much alike (see Figures 13 and 14); as the root approaches maturity, however, and the center becomes pithy, there is evident progressive stages of differentiation within the same tissue from center to outside.

The combination of a number of different tissues or kinds of tissues in a single structure constitutes a plant organ. Thus, most leaves consist of several different kinds of parenchyma, together with some vessels for the transport of water and food materials and perhaps some fibers for mechanical strength and support. The three main organs possessed by all of the higher plants are roots, stems, and leaves.

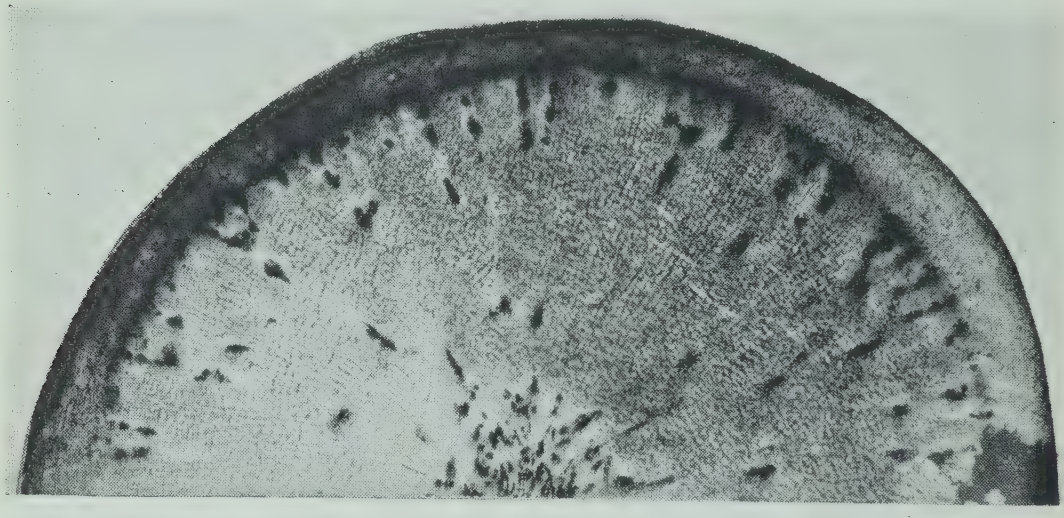

FIG. 13. Cross-section of half of a radish root made at a stage when it was in prime eating condition. Note the small amount of pith tissue at the center and the rather thick cortex or bark. Most of the tissue between pith and cortex consists of parenchyma. The vascular bundles, showing in cross-section as irregular, radially disposed, dark areas in the photograph, are not prominent or tough enough at this stage to destroy the crispness of the radish. Enlarged about ten diameters. Compare with Figure 14.

THE ROOT

The root is primarily an organ for the absorption of water and nutrients. Secondarily, it serves as an anchor for the plant, holding it in place. As the plant becomes older and the root system more extensive, its older portions come to play a relatively less important role in absorption and take on the added functions of transporting water and nutrients from the younger roots to the above-ground parts. It also serves as a storage organ for food materials manufactured by the leaves.

THE ABSORBING PORTION OF THE ROOT

The very tip of the growing root consists of a mass of cells much alike in size, shape, and general appearance. A little way back from the tip some differentiation is evident. Some of the surface cells in this region have grown out to form fingerlike or threadlike projections, the *root hairs*, that find their way between soil particles. These are the active absorbing organs, being responsible in most plants (the roots of some plants, for example, the Scotch pine (*Pinus sylvestris*) do not possess root hairs) for three fourths to nine tenths or more of both nutrient and water absorption. This is because they possess many times as much surface absorbing area as the exterior of the root cylinder itself and because their walls are thinner and more permeable than those of epidermal cells of the older portions of the root. Toward the center of the root and in that portion where root hairs have developed from the outer layer of cells some of the cells become much elongated, and their walls become thickened; some become fibrous, and others

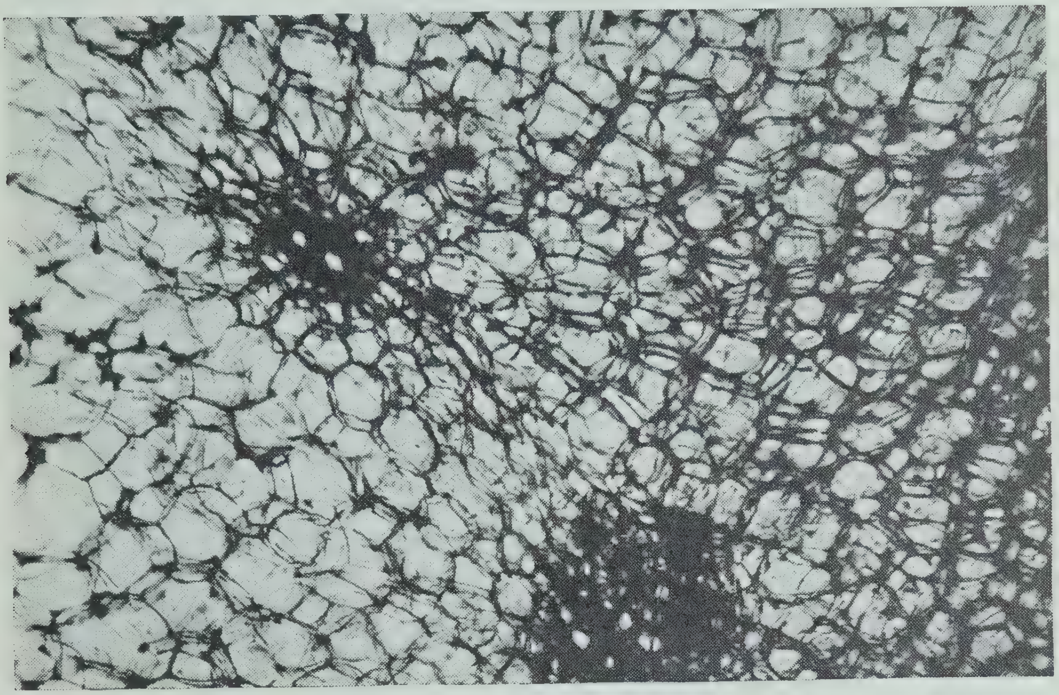

Fig. 14. Greatly enlarged view of a portion of the cross-section of the radish root shown in Figure 13. Note the dark lignified vascular tissue surrounded by parenchyma.

tubular as they differentiate. These cells are arranged in strands or bundles and are called *vascular bundles* or *fibrovascular bundles*. Their protoplasm disappears as they mature, and what results is essentially a system of pipes or tubes for the transport of water and solutes from the region of their absorption by the root hairs to the stem and leaves above ground.

As the roots extend farther and farther into the soil, the formation of new vascular or conducting tissue keeps pace with the extension, the ultimate result being a much ramified water- and nutrient-transport system below ground that connects the rapidly multiplying root tips with the stem above ground. Ordinarily the root hairs live and function for only a short time, new ones being formed continually just back of the advancing root tip, though in a few species, such as the honey locust (*Gleditsia triacanthos*), they may live for several months or even years. As they die and decay, the epidermal cells around and above them become somewhat thicker walled, but continue for a while to absorb very small quantities of water and nutrients. Eventually, however, the epidermal layer is cracked and broken as a result of pressure from the expansion of the various differentiating tissues that it surrounds, and in due course of time disintegrates and disappears.

THE CONDUCTING PORTION OF THE ROOT

In older portions of the root where differentiation has proceeded further there are three distinct layers: bark, wood, and a *cambium* or "sap" layer in between.

As seen with the naked eye, the cambium layer is little more than a line between bark and wood. In reality, however, it consists of one or several thicknesses or layers of meristematic cells that, like those of the growing root or stem tips, are undifferentiated. That is, they are more or less cubical, roundish, or rectangular in shape, very thin walled, filled with protoplasm, and either in an active condition of growth or, if dormant, capable of resuming growth when conditions become favorable. Indeed, their principal function is to divide and subdivide, giving rise to new cells that in turn may become differentiated into one or another of the various tissues of the wood or bark, depending on whether they are on the wood or bark side of the center of the cambium layer. When the cambium layer is in a dormant or quiescent state, its cells adhere to each other closely, and the cell walls are apparently tougher than at other times, for the bark does not separate readily from the wood. Under these conditions we say the bark "sticks." When they are in an active state of growth, the bark separates readily from the wood. In this case we say that the bark "slips" and that the "sap is rising," though any upward movement of water and nutrients is in the conducting tissues of the wood rather than in the cambium layer while at the same time there may be a downward, upward, or lateral movement of other materials in the bark.

Though we speak of the outer layer of the older root simply as *bark*, it is not of uniform or homogeneous structure, and it includes several different kinds of tissue. Its inner portion consists largely of elongated, thick-walled cells, tubular or ductlike in nature, that serve for conduction or transport of food materials manufactured by the leaves down to or toward the roots. This portion of the bark is known as the *phloem*. The outer portion of the bark eventually becomes more or less corky in nature and is spoken of as *cortex*. The cork and other tissues of the cortex are formed by a differentiation of parenchymatous cells originally derived from the cambium layer, though these undergo less change in shape than those of the phloem.

Similarly the woody cylinder of the root is not of entirely homogeneous structure. In its formation long, thick-walled, woody fibers and tubes are differentiated from the inner cells of the cambium layer while other cells become somewhat thick walled without such great change in shape. Together the woody tissues are known as *xylem*. The tubular portion of the xylem serves to transport water and its dissolved nutrients from the roots upward to the stem, where the stem's transport system "takes over." Tissues of both bark and wood whose cell walls are somewhat thickened, but in which there are still fairly large cell cavities and in which changes in cell shape are not so pronounced are classified as *wood parenchyma*. These cells usually remain alive much longer than those of the phloem or xylem fibers and ducts. As already indicated their most important function is for the temporary storage of food materials that are not required immediately for growth processes. In some of the fleshy roots, as those of the beet, turnip, dahlia, and sweet potato, a large portion of the root tissue consists of storage parenchyma (see Figure 13).

The roots of plants present almost as great a diversity of form and structure as their above-ground parts, though this is not generally recognized for we see less of them. Thus, the taproot of the young walnut tree is as different in shape and spread in the soil from that of the corn or wheat plant as is the top of a mature pine tree from that of the ivy that may spread over a rock pile at its base. The above-ground roots of the bald cypress (*Taxodium distichum*), banyan (*Ficus benghalensis*), mangrove (*Avicennia nitida*) or the walking tree of the Amazon Valley are as different from ordinary roots in form and function as are the underground stems of quack grass (*Agropyron repens*) or the above-ground stems of the organ cactus (*Lemaireocereus weberi*) from the trunks and branches of an apple tree.

Roots of most plants are sensitive to environmental influences: They grow toward and expand in a favorable environment and turn away from one that is unfavorable. Thus, roots of the beet or carrot become branched and malformed if they are grown where there is a high water table, just as they do if there is a rocky impervious subsoil. One of the reasons for preparing a deep, as well as mellow, seed bed for the so-called *root* crops is to secure straight, symmetrical, unbranched roots. Tree roots will enter a drain pipe through a crack and grow and branch and plug the drain in order to absorb water and nutrient materials that the drain carries. This is one of the reasons why greater care is necessary in laying tile in an orchard than in land devoted to raising annual crops.

Aerial roots form freely on many land and water plants in a favorable moist atmosphere (see Figure 78), sparingly or not at all in a dry atmosphere. Still other plants, the *epiphytes*, produce aerial roots only. These plants become anchored to the stems or branches of trees by either root or stem structures, but apparently the trees serve only for mechanical support, and water is obtained by the aerial roots from the moisture-laden air, while mineral nutrients are absorbed from dust particles brought to them and lodged on their surfaces by wind or rain. The aerial roots of many plants are fleshy or semifleshy, owing to a thick layer of parenchymatous cortical tissue between the epidermis and the central conducting vessels that functions as a reservoir for water storage. Among the plants of horticultural importance that depend largely on aerial roots are many of the orchids.

Roots of most plants branch freely. There is no regularity or system to their branching, at least in the sense that there is in the case of stems. Except for certain plants, for example, the beet, where branch roots have a more or less bilateral arrangement on the parent taproot, branches may arise at any point. Roots do not have joints or nodes like stems. Normally, roots of most plants do not form buds, and consequently they cannot be propagated by means of root cuttings. Some kinds, however, as the blackberry, sweet potato, *Anemone japonica*, *Bouvardia*, and many weeds form adventitious buds freely on their roots, and such plants are regularly propagated by means of root cuttings. In general, the ability to form adventitious buds on roots and thus to be propagated from root cuttings is regarded as a distinct disadvantage on the part of those domesticated plants that are commonly grown in hills and given row cultivation, for they are much subject to "suckering." Thus, one reason for budding or grafting the lilac (*Syringa vulgaris*) on privet (*Ligustrum vulgare*) stock, and many other plants on certain stocks commonly used for them, is to prevent their throwing up a mass of suckers from their roots, as they do when grown on their own roots.

THE STEM

There are many points of similarity between the structure of stems and of roots. Thus, the cells of the rudimentary stem in the seed closely resemble those of the rudimentary root, and as the stem elongates, its growing tip similarly consists of roundish, cubical, or rectangular, thin-walled meristematic cells. In slightly older portions of the stem, where some differentiation has taken place, the epidermal layer becomes relatively thicker walled and thus protects the enclosed tissues from desiccation. Fibrous and vascular conducting tissue is differentiated some distance beneath the surface layer, and these fibers and ducts, arranged end to end and in groups, form bundles or strands, as in the roots. In one main group of the higher plants (the *dicotyledons* or *exogens*) these strands or bundles have a regular, systematic arrangement (that is, they are all more or less equidistant from the center and form a kind of ring) in the primary (or young) stem. This is shown in Figure 15. In the other main group of higher plants (the *monocotyledons* or *endogens*) they are not arranged in any such regular or systematic pattern but are more or less scattered at random throughout the stem cylinder (see Figure 17). Between the vascular bundles some differentiation takes place, though much less than in the bundles themselves or in the epidermal layer.

SECONDARY STEM STRUCTURE

Older portions of the stem in which differentiation has proceeded further have tissues comparable to those found in older roots. There is a woody central cylinder consisting of thick-walled fibers, conducting vessels, and wood parenchyma. This woody cylinder is covered by bark, which in turn has become differentiated into an outer cortical layer and an inner layer of fibrous and conducting tissue, the *phloem*. Between bark and wood is a thin layer of thin-walled undifferentiated tissue, the *cambium* (see Figures 16 and 19), which performs the same functions in the stem that its counterpart does in the roots. As in the root, the tubes or vessels of the wood transport water and nutrients in an upward direction from roots to leaves, and the vessels or ducts of the bark transport food materials from where they are manufactured in the leaves downward to where they are used or temporarily stored in the branches, stems, or roots. This difference in function between the conducting elements of the wood and the bark ex-

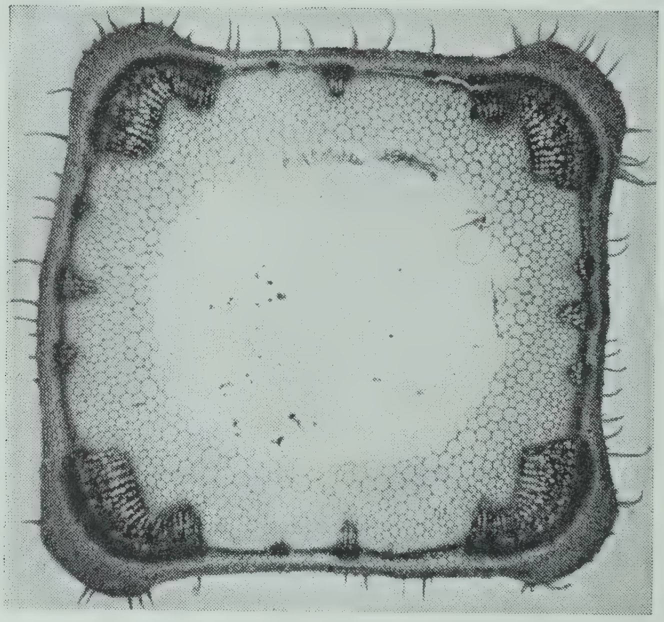

FIG. 15. Cross-section of an herbaceous stem (of the catnip plant) of the exogenous type. Differentiation has resulted in considerable vascular and fibrous tissue around the outside and especially at the corners and in pulling away of pith cells from the center. It is in this way that hollow stems arise. Enlarged about ten diameters.

plains the characteristic effects of mechanical injuries to the bark which result in more or less complete girdling of limb or trunk. If only a single limb is involved, that limb may live for many years, though it may make comparatively little new vegetative growth because of the heavy production of flowers and fruits brought about by the girdle confining the foods manufactured by its leaves to that portion of the tree. In the meantime the rest of the plant may show little response to the cutting off of the food supply manufactured by that portion of the top. Indeed, as far as

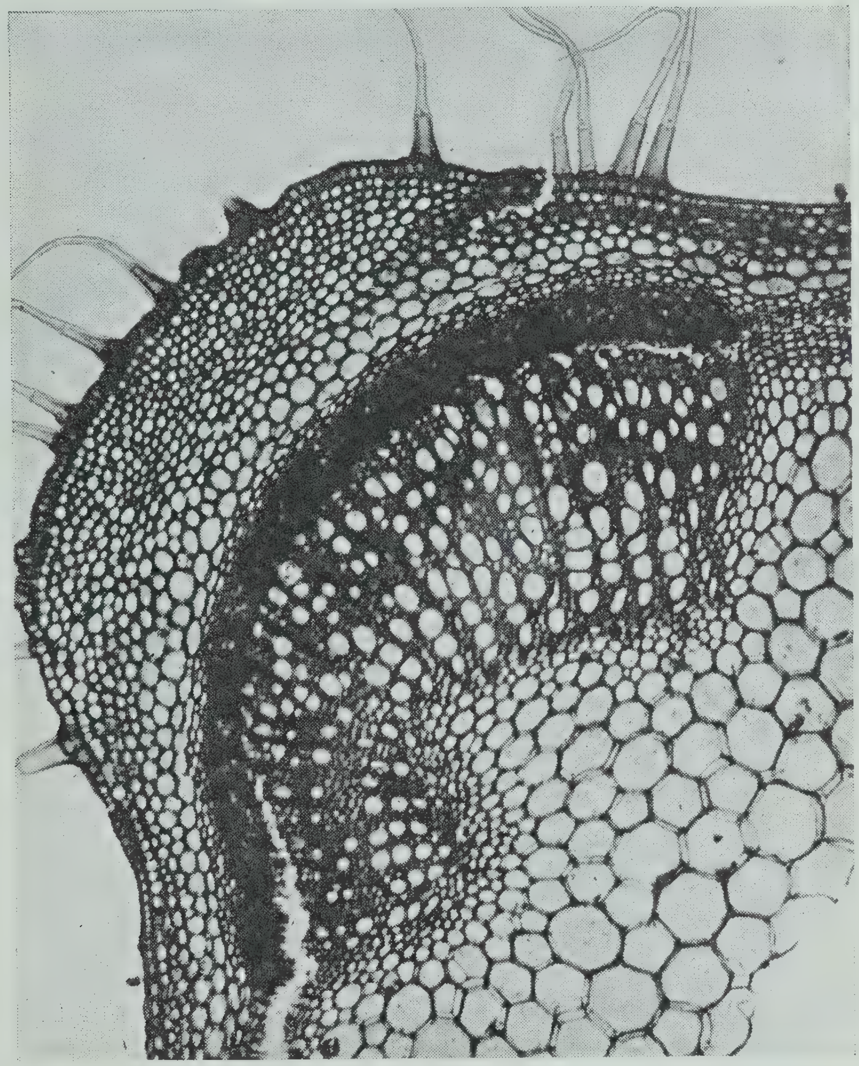

Fig. 16. One corner of the square catnip stem shown in Figure 15, greatly enlarged. Note the pith cells in the lower right-hand corner that have lost their cell contents, but that show little change in size or shape from their meristematic condition. The vascular tissue in the corner shows considerable lignification. There is likewise considerable thickening of cell walls in the bark layer, especially in the epidermis. Note, too, the hairs growing out from the epidermis.

the balance of the tree is concerned, the situation is comparable to that which would be obtained were the limb in question actually pruned away, except that the girdled limb still takes up room, casts some shade, and requires water and nutrients. On the other hand, if the main trunk or stem is girdled, the roots are entirely cut off from their supply of foods; their growth stops; and they die of starvation. The death of the entire top then follows.

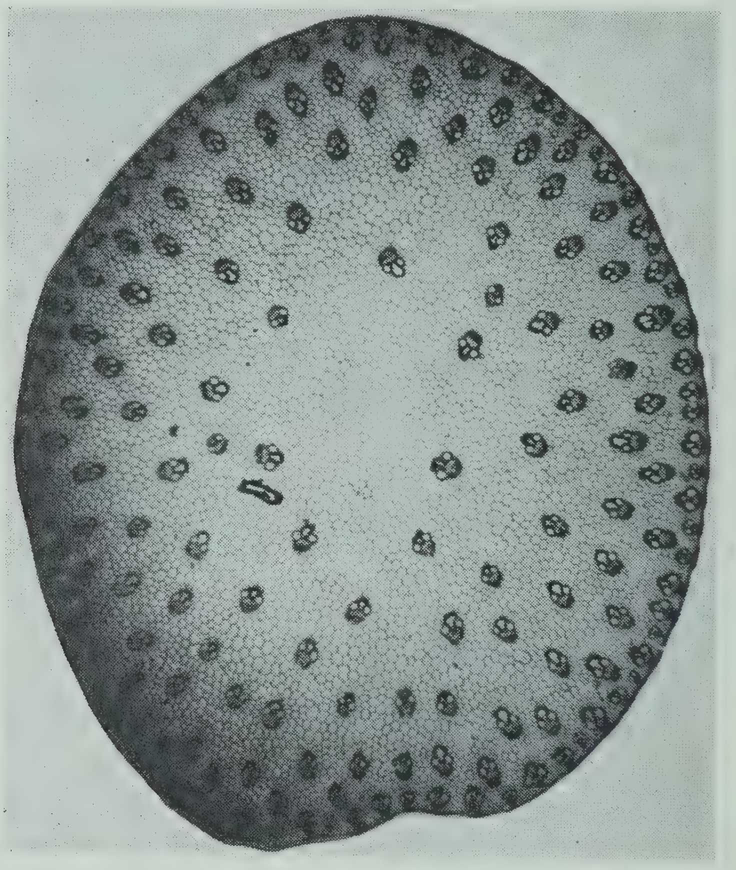

Fig. 17. Cross-section of an herbaceous stem (of a young corn plant) of the endogenous type. Note that the vascular bundles are scattered more or less at random throughout the stem and show no systematic concentric or radial arrangement such as is evident in the exogenous stem shown in Figure 15. Note, too, the absence of any distinct pith, wood, cambium, and bark layers.

The most readily recognized characteristic of stems that distinguishes them from roots is their *nodes* or joints at regular intervals. At each node is a leaf and in the axil of each leaf one or more buds. Branching occurs at the nodes as a result of the unfolding and subsequent growth of a bud.

The stems of different plants present a great diversity of form, though basically they possess the same structure. Many plants, for example, the strawberry and dandelion, are often spoken of as stemless. However, they possess very short stems that may be several times as broad as they are long. In such stems conducting tissues are subordinated to storage tissues. In some plants, as the common asparagus (*Asparagus officinalis*) and smilax (*A. asparagoides*), many of the stems and branches are much flattened and green in color, resembling leaves in general appearance and performing the ordinary functions of leaves, while the true leaves are reduced to small inconspicuous bracts. Such stems are called *cladophylls*, that is, leaf stems or leaf-functioning stems. A rather unusual type of cladophyll is shown in Figure 18. The plant (*Cytisus*) has two kinds of stems — ordinary round or cylindrical ones and also flattened, leaflike structures. The true leaves are reduced to small scalelike bracts from whose axils round stems, cladophylls, or flowers develop. Another interesting combination is found in the Tasmanian blackwood (*Acacia melanoxylon*). This tree produces ordinary cylindrical stems and cladophylls, like the *Cytisus* shown in Figure 18, while its true leaves are of the normal foliage type. In most of the cacti (such as is shown in Figure 59) the bulk of the stem tissue is parenchyma and is devoted to storage, though its outer layer contains green coloring matter and performs the functions of leaves.

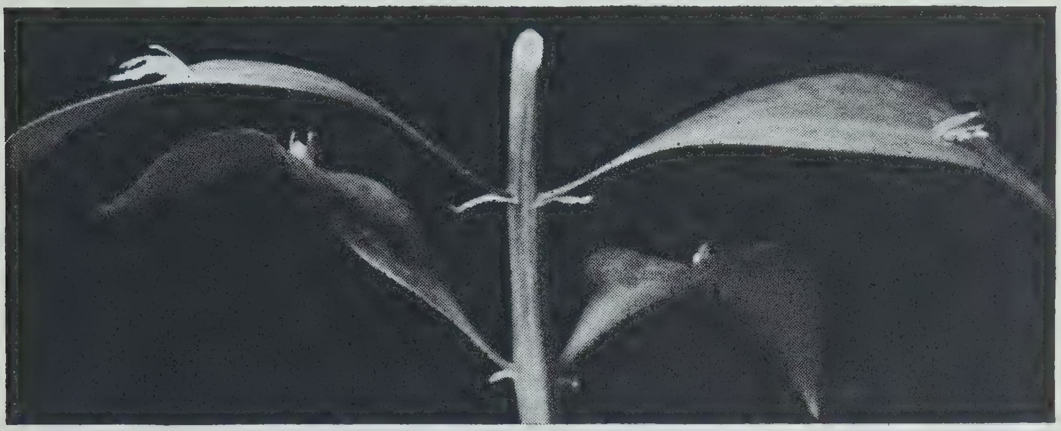

Fig. 18. Ordinary cylindrical stem and cladophylls of *Cytisus*. Note the small bractlike true leaves, from the axils of which both cladophylls and flowers have developed.

Ordinarily growth proceeds more rapidly in the spring and early summer than in midsummer and fall. Indeed, toward the latter part of the so-called *growing* season, growth in the sense of new tissue formation that results in an increase in size or bulk, may cease. The cells formed early in the season while growth is rapid are usually larger in size than those formed later. The result is that each season's layer of wood consists of an inner portion of coarser and an outer portion of finer texture, the one usually grading imperceptibly into the other. However, the coarse large-celled tissue formed early in the season usually contrasts sharply with the fine small-celled tissue laid down the preceding summer and fall, giving rise to the so-called *annual ring* shown clearly in Figures 19 and 21. Sometimes when environmental conditions lead to a complete stoppage of new wood formation in early summer and favorable growing conditions later result in a second period of growth, two rings are formed in a single season. Except

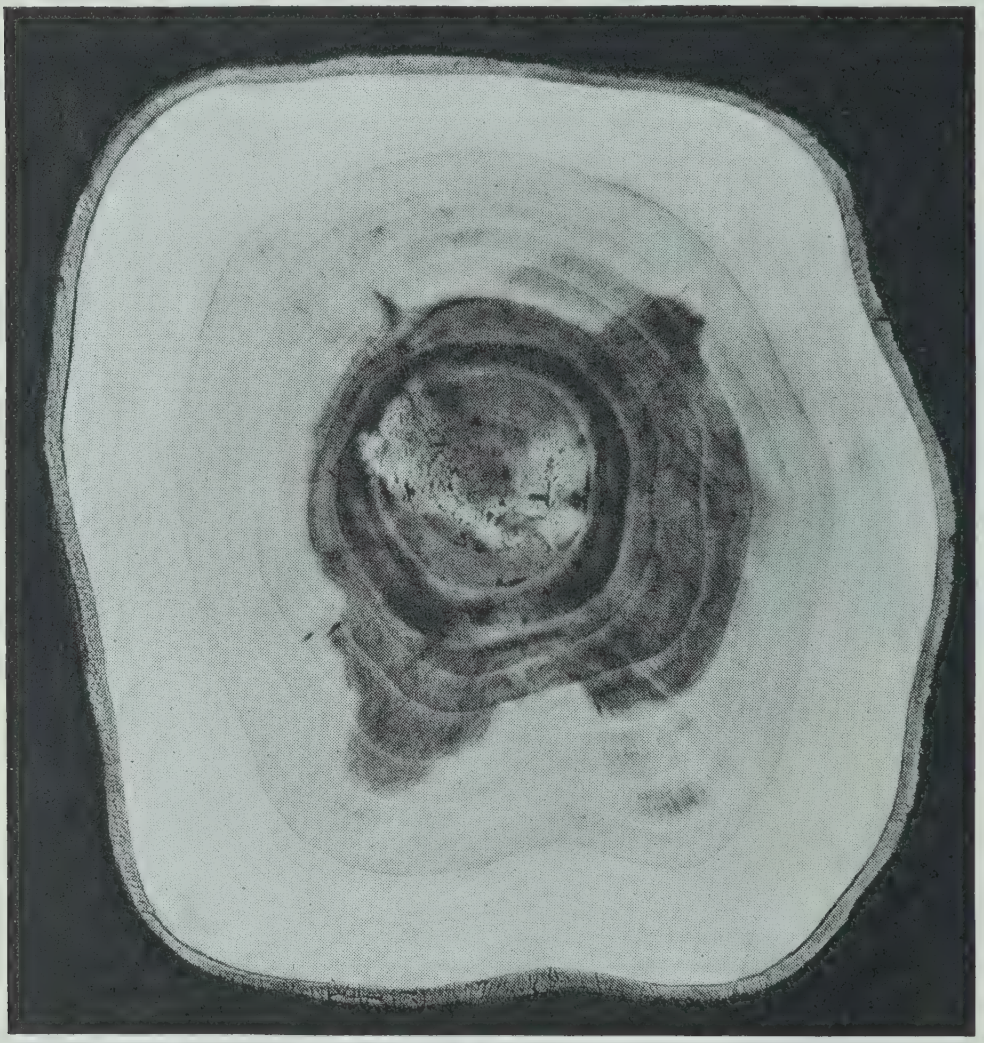

FIG. 19. Cross-section of a stem twenty-one years old. Note the variability in thickness of the annual rings, resulting in an unsymmetrical development. The outer light-colored portion is sapwood; the darker area near the center indicates heartwood. The lighter color of the heartwood at the very center indicates that heart rot has started. Note, too, the irregular outline of the heartwood.

for some difficulty occasioned by such false "annual" rings, the ages of trees or limbs can be determined from these rings.

As the wood in the center of the stem and its branches becomes older, various waste products are deposited in it and it becomes dark in color and physiologically inactive. In this condition it is termed *heartwood*, as distinguished from the younger, lighter colored, actively functioning *sapwood*. Heartwood is of further use to the plant principally as an element of mechanical support for branches and leaves. The rate of change of sapwood to heartwood varies greatly with different species and different conditions. It proceeds relatively more rapidly in slow growing than in fast growing, actively functioning tissues. It proceeds rapidly in the vicinity of pruning wounds or other mechanical injuries. It may take place more rapidly on a side of the stem or limb that is growing slowly than on another side where much new growth is taking place, the result being perhaps a layer of sapwood eight or ten years thick on the one side and only three to four years thick on the other. This is brought out in Figure 19. Conversion of sapwood to heartwood is hastened by severe cold of winter, especially under conditions of late fall growth and delayed maturity. Thus, it may be seen that the proportion of heartwood to sapwood is to some extent under indirect control. In the forest tree which is valued principally for the figuring and coloration of the lumber that is cut from it, a maximum quantity of heartwood is desired. In the orchard tree where we want the best possible water-, nutrient-, and food-transport system between roots and leaves in order to provide adequately for rapid growth and heavy fruiting, the slower the encroachment of heartwood on sapwood the better.

GROWTH IN LENGTH OF STEMS AND SHOOTS

As long as the plant lives, its stem grows in length as well as in circumference, that of the "stemless" plant increasing principally in circumference. Growth in length takes place only at or near the tips of the main stem and its branches. Here each shoot has a growing point, enclosed in a bud during its dormant season or resting stage and in a rosette of very young leaves during the period of actual growth, as shown in Figure 20. This growing point is a small mass of more or less undifferentiated meristematic tissue. This is the true tip of the branch. The cells composing this tissue are very densely crowded, full of protoplasm, and have very thin walls. Some of these cells divide very rapidly, giving rise to new cells, which form a dome whose apex is the growing point. Pressure from the growth and expansion of the tissues below and within pushes this dome outward, so that the newly formed cells are brought into a position parallel to the axis of the shoot while the growing point is simultaneously raised. These processes are continuous during periods of growth. For a time after they have come into position the newly formed cells continue to enlarge, the result being some length increase in the region just below the growing point. The extent of this increase in length is indicated by the distance between the points of attachment of the young leaves on the shoot as compared with the distance between the attachments of the fully formed leaves. Away from the tip, however, such increase in length does not occur; thus, if each of two buds, four or six inches apart, sends out a branch and the branches survive, their centers will be four or six inches apart ten or fifty years later.

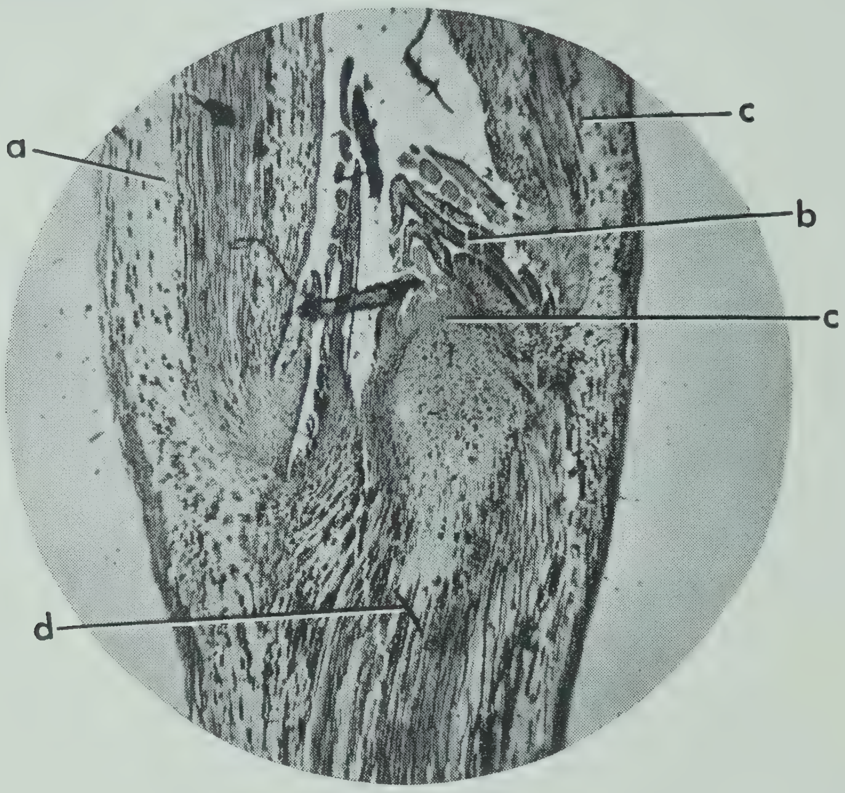

FIG. 20. The tip of a rapidly growing cherry shoot, greatly enlarged. a, petioles of partly grown leaves enclosing the growing point; b, rudimentary or embryo leaves; c, growing point of stem; d, portion of stem tip in which more or less differentiation has taken place.

In some species growth is more vigorous from the terminal than from any of its lateral buds. The result is a straight, upright, *excurrent* type of growth, as in the tobacco plant or pine or spruce of the forest. In other species growth from the subterminal buds is more vigorous than that from either terminal or more basal buds; the result is a spreading upright, or *deliquescent* habit, such as is found in a dahlia plant or an apple or maple tree. If the most vigorous growth is from basal or crown buds, there is produced a bushy or shrubby plant.

The stems of some plants are slender as compared with their height or length and the size and weight of the top that they have to support. The result is a failure to maintain an upright direction. They bend over, trail on the ground or over objects which are strong and rigid enough to support them. These are creepers or vines, either herbaceous or woody as the case may be.

CALLUS TISSUE

When a stem or branch is injured in such a way as to expose some of its cambium layer, either by removal of a portion of the bark or breakage or by pruning away some part, the exposed cambium cells or those immediately beneath which escape injury enlarge and divide, and these processes continue in the newly formed cells. The result is the formation of a mass of cambiumlike tissue that soon covers the points or areas originally exposed (see Figure 21). This is called *callus tissue*. As the mass of callus increases and with the lapse of time, some differentiation takes place, and the cells of the extreme outer portion become thick walled and corky. Eventually those adjoining the wood become thick walled and woody, while those between remain cambiumlike. As differentiation proceeds, the cells of the callus as a whole gradually become subject to much the same stresses, strains, and pressures influencing the layers of bark, cambium, and wood in the main stem and its branches, and eventually new growth and differentiation take place in the callus in essentially the same way as in the stem proper. This continues until the wound is completely healed. Since callus tissue is derived only from the cambium layer, the various tissues of bark and wood taking no part in the process, there is no vital connection between the callus and those layers of the wood and bark existing at the time the wound occurred, though those layers are completely covered over. This is illustrated in Figure 21 which shows a cross-section of a branch from which a small piece of bark had been removed. Callus tissues grew in from the edges of the wound until they met at its center, completely covering it. In the meantime, differentiation took place within these callus tissues so that when the stage shown in the picture was reached, the callus consisted of well-defined wood and

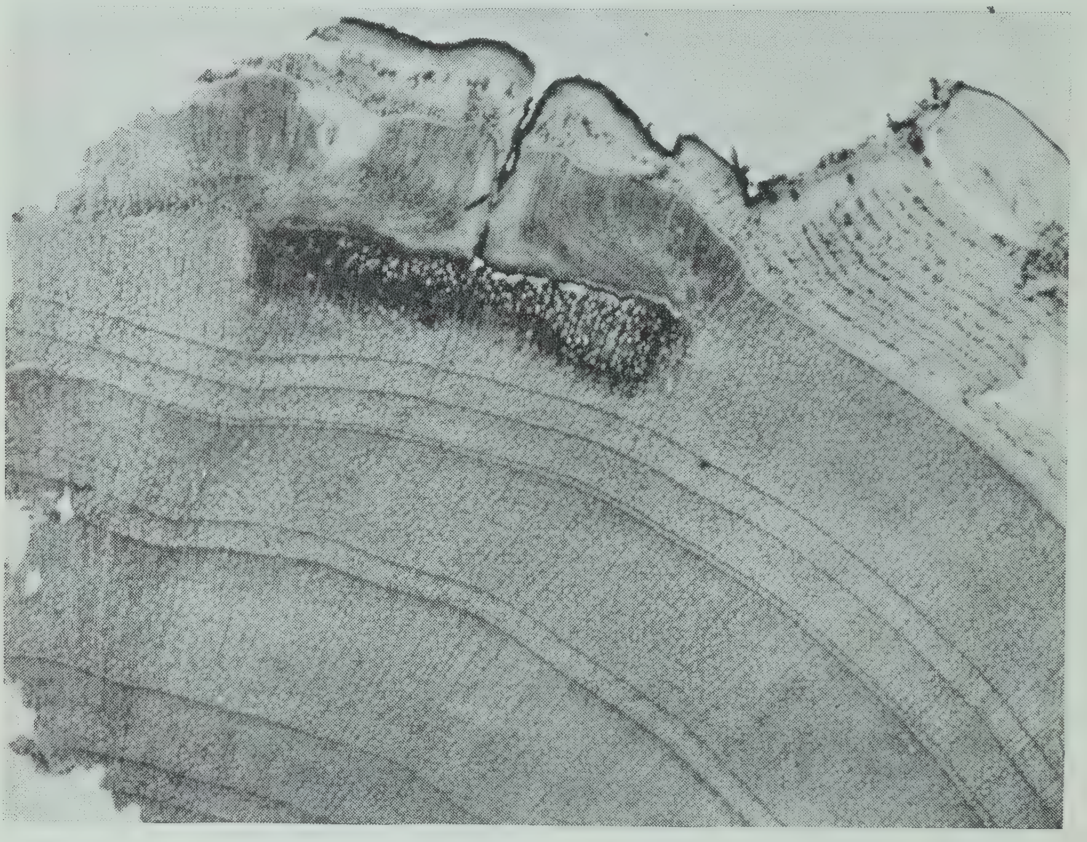

Fig. 21. An enlarged cross-section of a portion of a stem from which a narrow section of bark was removed. Callus tissues have grown in from its edges and met at the center of the wound. In the meantime, differentiation took place in the calluses. Note that their wood, cambium, and bark layers are continuous with the currently formed layers of wood, cambium, and bark of the stem proper, but that there is no vital connection between the callus tissue and the wood exposed by the removal of bark.

bark layers, separated by cambium that is continuous with the cambium of the stem.

The union of stock and cion in the grafting operation is effected through callus formation from the exposed cambium tissues of the two parts — callus formation that serves to cover over the wounded surfaces made in grafting or budding, much as is shown in Figure 21. Indeed, at one point where the two calluses are shown pressing together in Figure 21 a graft union has been effected, and their tissues have become continuous. This is brought out more clearly in Figure 22, which shows a longitudinal section of a stem from which a narrow ring of bark was removed. This was followed promptly by callus formation from both the upper and lower exposed edges of the wound. Relatively large masses of callus tissue were formed and soon came together near the center of the girdle. On the right side they have effected a complete union; on the left side the union is only a little less complete. The wood exposed by removal of the bark has been completely sealed in, but the callus has not united with its dead surface tissues; nor can it ever do so. A cross-section through another girdled stem that has callused over in the same way is shown in Figure 23. The parts of the graft are so fitted together that the callus tissue formed by the one part promptly presses against that formed by

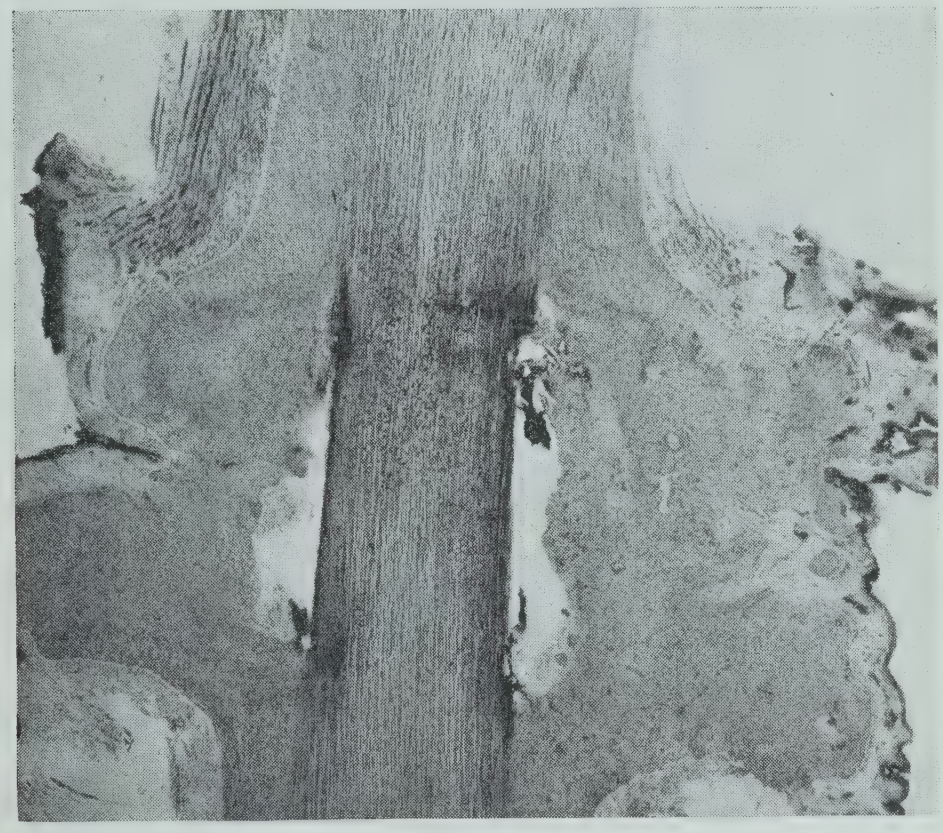

FIG. 22. An enlarged longitudinal section through a stem from which a narrow ring of bark had been removed and that has been completely sealed in by callus tissues developing from the cambium at the upper and lower edges of the wound. The union (essentially a graft union) of the two calluses on the right side is complete; that on the left is nearly complete. Note that the callus has formed no union with the desiccated, dead surface tissues of the wood exposed by removing the ring of bark.

the other part. Since the parts are firmly held in place, the cells of the two calluses soon dovetail and interlock, resulting in what amounts to a single mass of undifferentiated callus tissue. When differentiation takes place a little later, it occurs in both masses of callus and therefore across the line of interlocking cells of the two (the graft union), just as in Figures 21 and 22. The result is what amounts to a continuous cambium layer through the callus (as a whole) and therefore between stock and cion and, later, correspondingly continuous layers of bark and wood between the two, similar to those shown in Figure 21. The first essential to success in the grafting operation is so to fit the two parts together that their exposed cambium layers come into juxtaposition, for only by so doing will their callus tissues promptly meet and their differentiating cells form a "dovetail" joint.

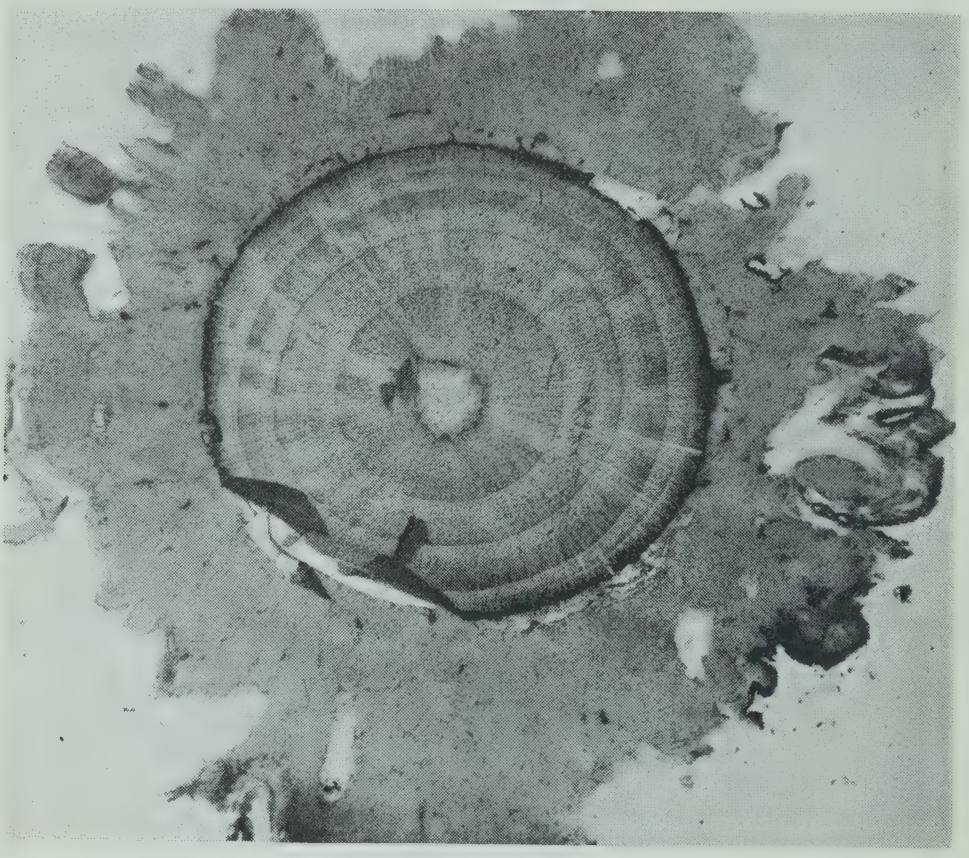

Fig. 23. A cross-section through a girdled and healed-over stem similar to the one shown in Figure 22. Note the irregular outline of the callus, suggesting how easy it is for one callus tissue to form a kind of dovetail joint or union with another with which it comes in contact in a graft union. Note, too, that the callus has not united with the girdled stem; it has simply enclosed it.

BUDS

A stem may be defined as a central axis of differentiated conducting and storage tissue consisting of bark, cambium, wood, and pith layers. It has joints or nodes at regular intervals, furnishing the points of attachment for leaves. A bud may be regarded as a rudimentary or embryo stem. It likewise consists of a central axis having nodes or joints, but it is a very short axis, often as broad or broader than it is long, with the nodes extremely close together and its cells as yet showing little differentiation, most of them being in a meristematic condition. Its leaves consist of overlapping scales protecting the delicate stem tissues within (see Figure 81). When conditions favorable for the growth of the buds appear, it unfolds to form a stem or branch.

Buds regularly develop at the nodes of stems in the leaf axils. Such buds are *axillary* or *lateral*, so-called because of their location in relation to the leaves that subtend them and to the shoot that bears them. Usually only a single bud is formed in the axil of a leaf, but in some plants, as the peach and Japanese plum, two or more are formed. The extra buds are spoken of as *supernumerary*. The tissues at the very tip of the stem or of its branches, though perhaps strictly stem tissues, often so closely resemble those of the bud in kind, arrangement, and appearance that they may be classified as a bud (Figure 20), though this may not be true of some stem tips during a period of active elongation. When most stems or branches cease growing in length for the season, they form *terminal* buds.

Seldom are buds formed between the nodes — that is, on the internodes. When they are so formed, they are spoken of as *adventive* or *adventitious* buds. Adventitious buds are likewise formed on the roots and even on the leaves of certain plants. Such plants, for example, the blackberry and the *Bryophyllum* (see Figure 24), can be propagated by root and leaf cuttings, respectively. All buds thus may be classified as lateral, terminal, or adventitious, depending on their points of origin.

Ordinarily when we speak of stems we think of strictly vegetative structures. Eventually, however, most stems give rise to flowering and fruiting branches, the several parts of the flower and fruit representing modified stem or leaf structures. These flowering branches spring from buds. Some buds, therefore, must

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be flower buds, instead of vegetative buds. The flower bud differs from the leaf or vegetative bud principally as follows: Ordinarily it is somewhat larger and plumper (see Figure 85); in the bud itself the initial differentiation of flower parts has occurred, and as it unfolds, this differentiation is carried further, and flowers and fruits are eventually formed.

The bud provides a growing point from which a branch, vegetative or flowering as the case may be, may grow. Indeed, the normal thing is for the bud to develop into a branch, and this may take place either promptly after the bud is fully formed, or it may be delayed until some later time. If there is more or less delay between the formation or maturing of the bud and its unfolding into a branch, we speak of the bud as being *dormant* during that interval. As a matter of fact, most buds remain dormant for a shorter or longer period, and many of them never open. Whether or not they vegetate, and if they do, the question of when they vegetate, depend on a number of conditions — including favorable conditions of temperature, humidity, light, food and nutrient supply, and likewise conditions of balance or equilibrium within the plant itself. If a bud remains dormant for more than a year after its formation, it becomes *latent*. By this we mean that it enters a condition in which it is likely to grow only as the result of some rather unusual stimulus. In plants that are propagated by means of cuttage or graftage and that propagate readily by these means, young wood (that is, shoots of the current or pre-

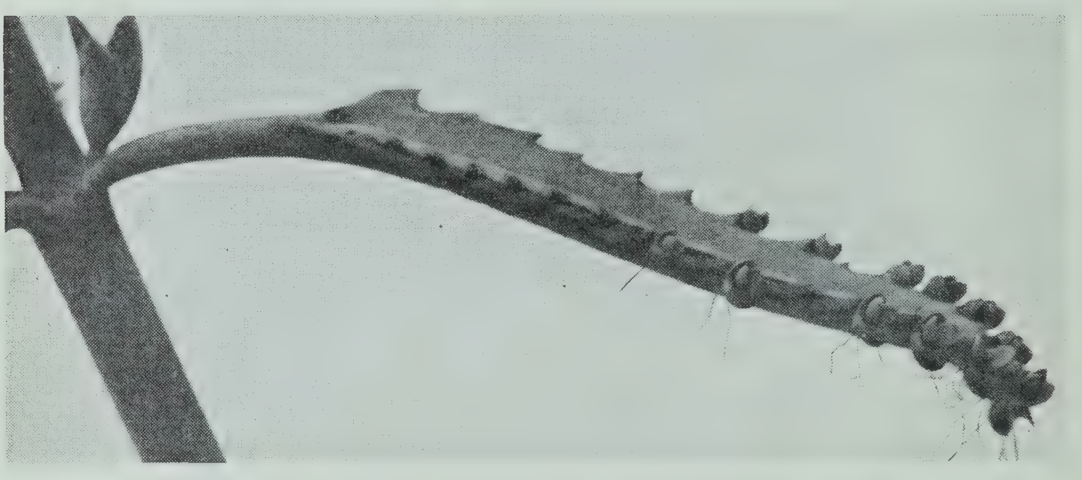

Fig. 24. A *Bryophyllum* leaf showing the development of adventitious buds in the notches along its margin. These drop off and quickly take root in any favorable medium. They often form aerial roots before becoming detached from the parent leaf.

ceding year, with *dormant* buds) is preferred for cuttings or cions. It forms callus tissue and strikes root more readily than older wood. In those which are similarly propagated but which propagate with considerable difficulty, older wood with small *latent* buds is preferred for cuttings and cions because their buds are slower to "break," thus giving greater opportunity for new roots of the graft union to establish contact with a water supply before it is needed. Furthermore, the older wood is likely to be better supplied with stored foods from which callus tissue and roots can be formed. These differences are brought out clearly in Figure 25 which shows different types of cion wood of the Japanese walnut (*Juglans sieboldiana*).

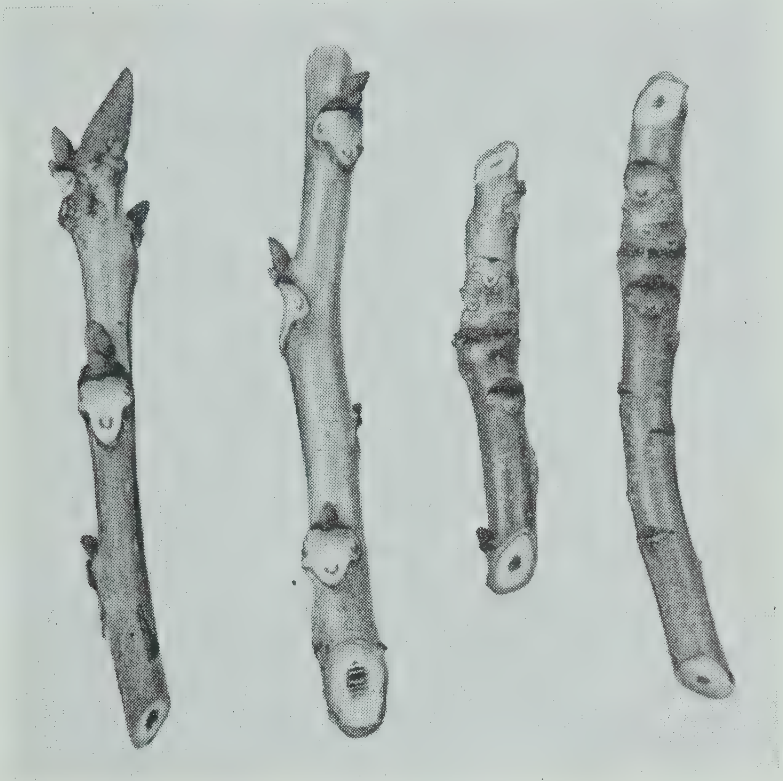

FIG. 25. Cions of the Japanese walnut (*Juglans sieboldiana*). The terminal portion of a shoot on the left has large buds, rather soft wood and a relatively large pith. It makes poor cion wood. The two on the right include portions of two-year-old and of one-year-old wood. Their buds are small, their wood hard, and the pith small in amount. Wood of this type makes the best cions. The second piece from the left is from the median portion of a shoot and makes a satisfactory cion.

In some species, as the walnut, the older buds abscise, that is, they break or fall off. In others most of them live indefinitely, being carried out from where they are formed on the stem by the laying down of the annual rings of wood underneath them, but becoming more or less deeply buried in the bark. Though almost microscopic in size these latent buds are not "floating" or loose in the bark but continue to be attached to and directly connected with the annual ring with which they originated by a few fibers of vascular tissue. In brief, they are buried buds terminating buried branches that are often of microscopic diameter, though eventually of considerable length. When a limb or stem of some size is cut off, the numerous shoots that spring from near the cut edges of the bark come from these latent buds — or, in some instances, from adventitious buds developing directly from the cambium layer or from a cambium-derived callus at the point in question. In general parlance *watersprouts* are vigorous shoots springing from either latent or adventitious buds on stems; *suckers* are similar growths springing from adventitious buds on roots.

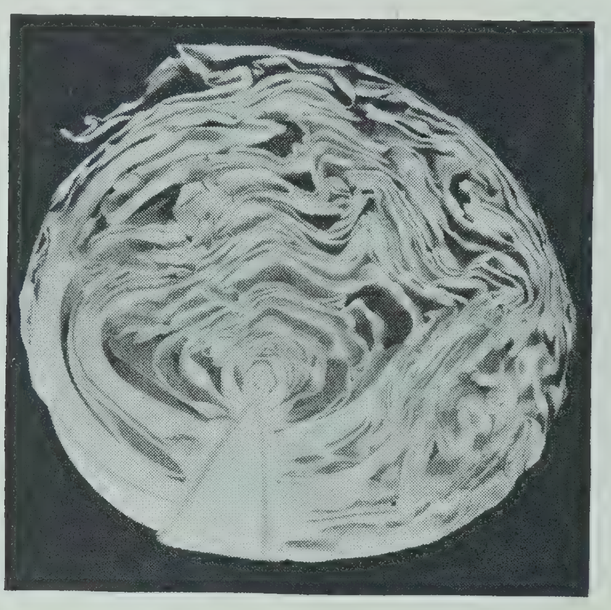

Fig. 26. Longitudinal section through the head of a cabbage, showing its close resemblance structurally to a bud.

Though perhaps more properly considered along with stem structures, attention may be called to more or less oval or spherical woody bodies. *Wood kernels* is a fairly accurate descriptive term for these, frequently found embedded in the bark of trees of many kinds. They are in reality blind, leafless branches consisting of a number of concentric layers corresponding to the annual rings of a normal branch, that have developed from the half-smothered growth of latent buds. Like true branches they have their nodes and internodes and are connected by a slender strand of fibrovascular tissue with the annual ring of wood with which they originated. These wood kernels, or bark kernels as they are often called, are sometimes used in the propagation of certain woody plants, for example, the olive, shoots growing out from their long-latent, diminutive buds when placed under proper conditions.

Though basically alike in structure, buds present great diversities in size, shape, and appearance. In size they range from the microscopic structures on the bark kernels, mentioned in the preceding paragraph, to the ten-pound terminal bud of the cabbage head which may constitute four fifths of the weight of the entire plant and which is essentially a storage organ (Figure 26). The cloves of commerce are the dried, unopened flower buds of a tropical tree (*Eugenia aromatica*) belonging to the myrtle family. The globe artichoke (*Cynara scolymus*) is the large scaly terminal flower bud of a plant related to the common thistle, though in appearance this bud looks more like an Easter lily bulb than like a bud.

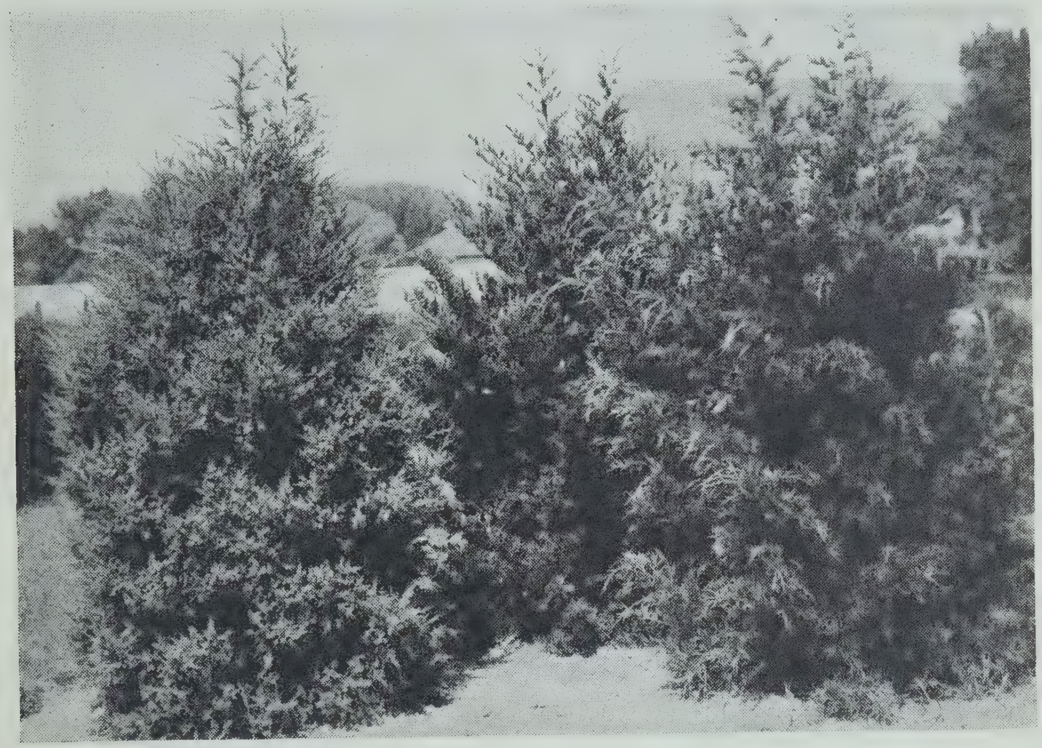

Fig. 27. On the left a small tree of the common juniper (*Juniperus virginiana*), showing its juvenile type of growth; on the right a tree of the same species showing its mature type of growth. Individual branches of the juvenile and mature forms of this species are shown in Figures 28 and 29.

Leaf buds on the same plant that are alike in appearance in some instances develop into branches or whole plants, as the case may be, of very diverse characters. Thus, a terminal bud taken from the coffee tree or from many of the evergreens and used for propagation purposes will grow into a radially symmetrical, upright tree of *excurrent* type of growth like its parent; a tree similarly propagated from one of its lateral buds or from the terminal bud of one of its branches will develop into a tree with a spreading or sprawling or bilateral habit of growth. Such plants are said to possess *dimorphic* branches.

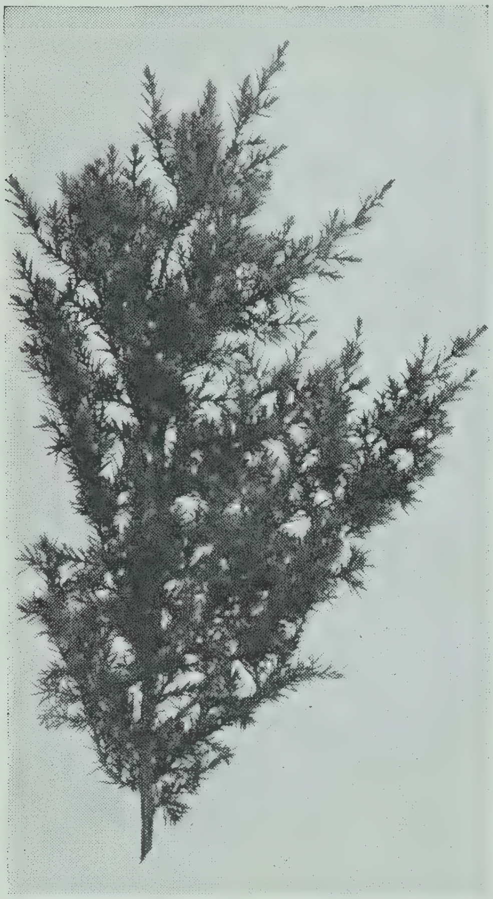

FIG. 28. A single branch of the juvenile form of the common juniper (*Juniperus virginiana*). Compare with Figure 29.

Another type of dimorphism is exhibited by certain species, notably some of the conifers, in which plants raised from seeds show a certain characteristic foliage, branching habit, and type of growth for many years; then they start producing leaves of an entirely different appearance and accompanying the new leaf type there may be a different habit of growth, illustrated by the trees and branches of the red cedar (*Juniperus virginiana*) shown in Figures 27, 28, and 29. Once the new or "mature" type of growth appears, it seldom or never reverts to its *juvenile* form, and cuttings or grafts made of the mature form yield plants of that type only. On the other hand, cuttings or grafts made of the juvenile form yield plants of that type only, or plants that, in some varieties, change to the mature form about when the original seedling from which the cuttings or cions were taken makes the change, and that in other varieties retain their juvenile form more or less indefinitely. Permanency of the juvenile form of cutting-propagated plants characterizes a number of horticultural varieties of several species of cypress — for example, *Chamaecyparis obtusa* and *C. pisifera*. So different are the juvenile and mature forms of certain species, and so long does the juvenile form persist that the two have often been mistaken for distinct species and propagated, catalogued, and disseminated as such by nurserymen. In the redwood (*Sequoia sempervirens*) the vigorous upright branches are characterized by appressed, ovate-oblong, spirally arranged leaves; lateral, weaker shoots are characterized by two-ranked, linear or linear-lanceolate leaves. A less striking, but none the less important type of diversity shown by buds of the same plant is exhibited and illustrated by the carnation. Propagators of this plant always take terminal cuttings of strong, short, vigorous crown shoots whose internodes have not yet reached their full length. Cuttings made from longer shoots whose internodes are fully developed may be rooted and reproduce the normal characteristics of the variety, but they give rise to weak, poor branching, unproductive, inferior plants, even with the best of care. Another illustration of this type of bud and branch diversity is discussed under "offsets," in the next chapter.

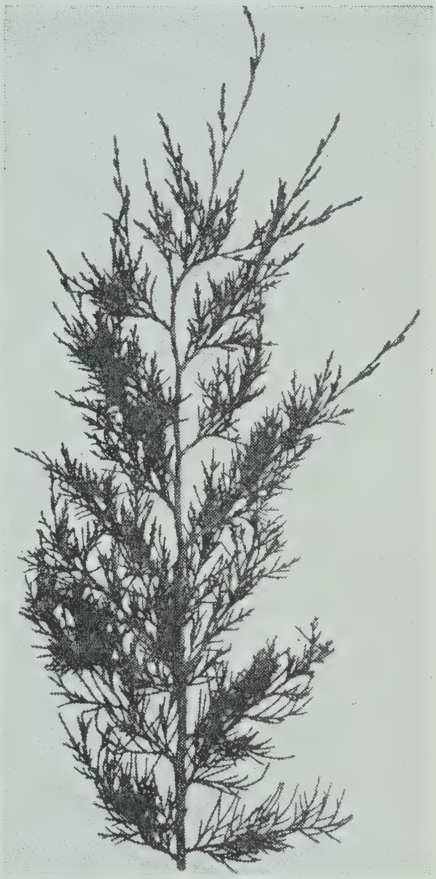

FIG. 29. A single branch of the mature form of the common juniper (*Juniperus virginiana*). Compare with Figure 28.

LEAVES

Leaves are the food manufacturing organs of most plants (cladophylls excepted). To them is brought a stream of water in which is dissolved various *nutrient* substances absorbed from the soil by the roots, and here they are combined chemically with carbon dioxide obtained from the surrounding air to make *food materials* — so-called, in distinction from nutrients obtained from the soil, because they are used by both plant and animal in the building of new tissue and in other growth processes. The leaves then are the laboratories or factories in which the synthetic, food-producing processes take place. Light furnishes the necessary energy.

This function of the leaf more or less determines the essential characteristics of its structure. It must be an organ that is exposed to the light, and theoretically it would therefore seem that maximum leaf efficiency would be obtained only with maximum exposure and the type of structure associated with it. In reality this is what we have in most leaves — a very thin bladelike organ in which the greatest possible amount of light can reach a given quantity or weight of tissue consistent with a reasonable degree of rigidity and firmness of texture to enable the organ in question to withstand wind, rain, desiccation, and other factors of environment.

Typically leaves consist of three parts: stipules, stem or petiole, and blade. The stipules are usually small, bractlike structures at the base of the petiole that in some plants remain attached to the stem as long as do the petiole and blade but that in many others drop off soon after the leaf unfolds. The principal function of petiole or leaf stem is to hold the blade out from the stem so that it will be exposed to the maximum amount of light. In addition it provides conducting tissue for the transport of water, nutrients, and foods between the stem and the leaf blade. In some plants, for example, rhubarb and celery, the petiole contains considerable parenchymatous tissue that serves for storage.

The leaf blade typically is characterized by an upper and lower epidermis whose cells are considerably thickened on the exposed side. Often the protection that this layer provides for the tissues within is aided by the deposition of a thin layer of cutin or wax, especially on the upper surface of the leaf — hence its name *cuticle* or *cuticular layer*. Immediately beneath the upper epidermis there is a layer of closely packed, elongated cells, called *palisade* cells from their shape, that are well filled with protoplasm containing many chloroplasts. These are in reality specialized parenchyma cells, sometimes called *chlorenchyma*. It is in these cells that much of the synthesis of food with the aid of sunlight, takes place. Between the palisade cells and the lower epidermis is a loose network of thin-walled, irregularly shaped cells of various sizes and shapes that together constitute a kind of spongy layer or mass of tissue. This spongy parenchyma, often designated as *mesophyll*, encloses many air spaces that together often bulk larger than the cells themselves. It, too, functions in the synthesis of organic food. Scattered irregularly over the lower surface of the leaf are many small openings or pores, the *stomata*. Each stoma is surrounded by two, semicircular, so-called *guard* cells, which, by contracting or expanding, are able to open or close the opening between them. These guard cells are very sensitive both to light and to the supply of water that reaches them. Under the influence of light they cause the stoma to open; during periods of darkness they close the stoma and cause it to remain closed in most plants. If the supply of water reaching them is something less than is necessary to keep them turgid (that is, plump) during the hours of daylight, the slight wilting to which they are subject automatically closes the opening between them. The stomata open directly into the intercellular or open spaces of the spongy parenchyma and provide the means for an interchange of gases between the inside and outside of the leaf. In the main this interchange consists in an intake of carbon dioxide and the egress of oxygen and water vapor during the daylight hours. During darkness relatively little water vapor escapes from the leaves because of the closing of the stomata, and what is lost escapes largely through the cuticle. This latter is referred to as *cuticular transpiration;* that vapor escaping through the stomata as *stomatal transpiration.* In the absence of light internal respiratory processes within the leaf result in the accumulation of carbon dioxide within the mesophyll cells themselves; this in turn passes through their cell walls into the intercellular spaces, from which it slowly escapes to the outside air through the almost closed stomata.

THE PLANT AS A WHOLE

The plant as a whole is thus seen to consist of three main structures — root, stem, and leaf. No one part is more important than the others; indeed no one part can exist, except in a few special cases or under a few special conditions, without the other two. In one sense, however, the leaf occupies a key position in the plant economy (except for the cladophylls), for it is there that the water, nutrients, and carbon dioxide are brought together to be built into food substances that in turn return to the root, and to all other parts of the plant, for use in building their tissues and supplying the wherewithal for their maintenance. Without a well-developed, efficient leaf system neither the plant as a whole nor any part of it can attain maximum development. It is not just accident that a relatively large portion of agricultural and horticultural practice, from cultivating and fertilizing to spraying, from thinning and staking to a well-performed job of pruning and trellising, is directed toward producing the largest and best possible leaf system and then toward keeping it in as nearly perfect condition as possible, spread out so as to intercept the maximum amount of sunlight.

GROWTH PERIODICITY

The three main growth processes that were briefly discussed in the first portion of this chapter — cell division, increase in size, and differentiation — include the major part of the plant's vegetative activities. Each process, however, is subject to almost infinite variation in detail. All are subject to variation in speed or rate, giving rise to the phenomenon known as *growth periodicity*.

Though in no case does growth take place so rapidly that the observer can actually see it, observation at hourly, daily, weekly, or perhaps longer, intervals reveals the fact that changes have been in progress, and the natural assumption is that they have been steadily going on. Closer examination, however, indicates that growth is not a steady process that proceeds at a uniform rate for any considerable length of time. There are periods of rapid growth followed by periods when it is less rapid or perhaps when it ceases. Or growth may proceed rapidly at one place or in one part of the plant and then slow down or cease while it takes place more rapidly somewhere else. We recognize this tendency or characteristic in plants when we speak of their "flushes" of growth. Sometimes these alternating periods of rapid and slow growth are obviously due to conditions of environment, as periods of drought following periods of abundant rainfall, or periods of high temperature following periods of low temperature; sometimes they are more or less independent of environment and apparently due to internal conditions within the plant. It should be stated, however, that often the periods of apparent quiescence, when seemingly little or no growth (growth in the form of increase in bulk) is taking place, may be periods when some of the growth processes other than cell division and increase in volume are most active. Furthermore, these other growth processes are fully as necessary as cell division and increase in bulk.

There comes a time when the fruit-grower wants his trees to stop growing and harden their tissues so as to withstand the rigors of the coming winter, when the potato-grower wants his plants to cease growing tops and start forming tubers, when the chrysanthemum-grower wants his plants to make no more vegetative growth but to come into blossom. To some extent these periodicities of plants, at least the length and intensity of the alternating growing and quiescent periods, are under the grower's control through such measures as irrigation, the application of fertilizers, the modification of temperature. More will be said of this later. To some extent, however, they are entirely beyond his control, for there are periods during which no cell division or increase in size of cells or mass of tissues will take place, even though external conditions are provided that at other periods are ideal for these same processes. We say, then, that the plant or certain of its parts are in a *rest period*. Thus, a lilac branch brought indoors in early or midfall cannot be forced into blossom, though it blossoms promptly if brought in after midwinter. In the case of seeds this period is sometimes spoken of as an *after-ripening* period. Seeds of the stone fruits will not germinate promptly and freely if planted right after harvest but must first go through a period of rest. Often this resting or after-ripening period can be greatly shortened by properly subjecting the part in question to heat or cold or by etherizing it or treating it with some other chemical. Incidentally, this behavior is in sharp contrast to that of the so-called *viviparous* seeds of certain plants that germinate before they are liberated from the plant that produces them. The factors which cause the initiation and, later on, the breaking or disappearance of the rest periods, are not well understood, though apparently obscure chemical changes are involved. These changes, too, are as truly growth processes as the more obvious cell division or increase in cell size and tissue mass that may precede or follow the rest period.

It should not be inferred from what has been stated that all plants are alike in their periodicities or even that all plants are periodic in their growth. Some, apparently, if constantly provided with conditions favorable for growth, will continue to grow indefinitely. This seems to be true of the leaves, stems, crowns, and roots of many grasses. Only drought or cold or high temperature or some other extreme of environment enforces a slowing down or cessation of vegetative growth. Wheat will sprout in the shock if it is hot and humid at harvest time, indicating either the complete absence of or a very slight after-ripening period. On the other hand, the seeds of the blueberry, even if sown immediately after removal from the fresh fruit, refuse to grow until they have undergone a period of rest, shorter than it otherwise would be if accompanied by chilling. The greenhouse *Tradescantia*, *Geranium*, and *Coleus* will continue to grow indefinitely if they have suitable light, temperature, moisture and nutrient supply, together with plenty of room. Under the same conditions the croton grows intermittently. Roots apparently do not have resting periods, or at least their resting periods are much less pronounced than those of above-ground parts. Knowledge of periodicities of plants furnishes the propagator and grower with clues as to how they should be handled under cultivation. In general, the less prominent the resting period of a plant the more readily does it lend itself to greenhouse culture where rapid continuous growth gives greatest return on the investment in space, heat, and care.

The resting seed, bud, bulb, branch, or plant is necessarily dormant, that is, no apparent growth processes are under way. The dormant seed, bud, bulb, branch, or plant, however, is not necessarily in a resting condition. Thus, a fall-planted spinach plant becomes dormant when it stops growth because of cold weather, and it goes through the winter in a dormant condition. It is not in a resting period, however, because it can, and does, resume growth at once upon the appearance of favorable weather. Were it in a resting condition it couldn't resume growth regardless of how favorable the conditions. *Dormancy* is the broader term, implying simply cessation of growth from any cause whatsoever. Resting period implies inability to grow (that is, inability for cell division to take place) for the time being, regardless of environmental factors.

PROBLEMS

1. Why, in general, is heartwood darker in color than sapwood rather than the reverse being the case?

2. In tying single-stem tomato vines or chrysanthemum plants to stakes, can they be tied tightly, or must they be tied loosely so that the strings can be pulled (slipped) upward along the stakes as the plants grow and become taller? Explain.

3. A board freshly sawed from a log may be expected to warp as it dries, unless special precautions are taken. Which portion of a board that is cut partly from sapwood and partly from heartwood would you expect to warp the more? Why?

4. As between roots and stems, in which organs would you expect the more extreme differentiation? (*a*) In their storage tissues? (*b*) In their

conducting tissues? (*c*) In the tissues that provide mechanical strength? (*d*) In their epidermal and cortical tissues? Why?

5. Would you expect wounds on the stems or branches of woody plants to heal most readily in spring, midsummer, or fall? Why?

6. Would the same answer apply to wounds on their roots? Explain why.

7. At what season or seasons of the year would you expect stock and cion to form a graft union most quickly? Why?

8. Certain kinds of wood-boring insects work almost exclusively in the sapwood; other kinds work almost exclusively in the heartwood. Which type would you expect to injure the tree more seriously? Why?

9. Would you recommend transplanting trees or shrubs that have a distinct rest period at or near the beginning of that period or at or near its end? Why?

10. Would you recommend sowing seeds that have a long after-ripening period before or after that period? Why?

11. Would you expect very slow-growing plants — for example, the walnut — to graft more or less readily than very fast growing plants — for example, the apple and willow? Why?

12. Examine a two-foot-long shoot from the top or outside of an apple tree and a watersprout of *similar length* growing out from its trunk or from one of its larger limbs, and compare them in diameter, number and length of internodes, size of buds. How do you account for the differences you find?

13. Examine some eighteen- to twenty-four-inch-long, unbranched peach shoots from the top or outside of the tree. At which nodes do you find single buds and at which ones two or three? How do you account for this distribution?

14. Obtain some three- or four-foot-long shoots from a standard, normal, upright growing willow, elm, mulberry, or birch and some shoots of the same length from a "weeping" variety of the same kind. Compare node number and internode length. Compare their basal, median, and apical diameters. What differences do you find, and how do you account for them?

15. The stems and main branches of vines are comparatively uniform in diameter while those of trees and shrubs taper more from base to apex. How do you account for this difference?

16. The trunk of a large tree that has grown up in the forest and has no branches within fifty to seventy feet from the ground is much more uniform in diameter than that of a tree of the same kind growing under conditions such that it has retained its lower limbs. How do you account for this?

CHAPTER IV

SPECIALIZED BUDS AND STEMS

ATTENTION has been called to the fact that the common or normal buds and stems of plants present great diversity in size, shape, and general appearance and that likewise they may serve many purposes. Besides what has here been termed *ordinary* or *normal* buds and stems, there are many *specialized* budlike or stemlike structures, though probably no sharp line can be drawn between those that would be classified as normal and those that are specialized. In a sense the terminal bud of the cabbage (Figure 26) or the lateral buds of the Brussels sprouts or the fleshy stem of the kohlrabi (Figure 41) are specialized structures. They differ from ordinary buds and stems in size and in the proportion of parenchymatous storage tissue; nevertheless, they are commonly thought of simply as buds and stems. Similarly most of the specialized bud and stem structures discussed in this chapter contain relatively large proportions of storage tissue. The part that they play in the propagation of the plants that form them, both in nature and under cultivation, calls for special consideration.

BULBS

A bud has been defined as a rudimentary or embryo stem — in other words, a young and very much shortened central axis with regularly spaced nodes at each one of which is a rudimentary leaf or leaf scale (see Figure 81). At least the stem tissues of the bud have undergone little differentiation, being in more or less of a meristematic condition.

If such a typical bud increased greatly in size and, as it grew, its stem portion increased in diameter much more rapidly than in length or height, and if at the same time its rudimentary leaves grew rapidly but, instead of unfolding into ordinary leaves with prominent blades, formed much thickened, fleshy overlapping scales, resembling the scales of ordinary buds except for being much larger, thicker, and fleshier, the resulting structure would be called a *bulb*. This is essentially what we have in the onion, hyacinth, tulip (Figure 30), narcissus, and many other plants. In reality the bulb is little more than a large fleshy bud, differing in structure from the cabbage head (Figure 26), which we ordinarily think of as a large fleshy bud in structure, principally in having a relatively shorter and wider stem and still more fleshy leaves. That is, in the typical bulb a relatively large portion of the tissue consists of bud scales (modified leaves) rather than of stem.

Compact bulbs, like those of the onion or tulip, in which each scale extends clear around or nearly around the axis and rather completely encloses the more central scales, are called *tunicated* bulbs. Those in which the individual scales occupy or are attached to only small segments or arcs on the axis or stem and consequently do not form such a compact structure are called loose *scaly* bulbs. Plants that produce scaly bulbs can be readily propagated by simply breaking them apart and planting the separate parts, each of which consists of one or more scales with a bit of the stem tissue to which they are attached. This is the method commonly employed with the so-called *multiplier* onion. The Easter lily (Figure 31), day lily (*Hosta plantaginea*), tiger lily (*Lilium tigrinum*), and many others are of this type. The bulb of the onion (*Allium cepa*) consists of many scales, that of the garlic (*Allium sativum*) of only a few. Between the different types are all gradations.

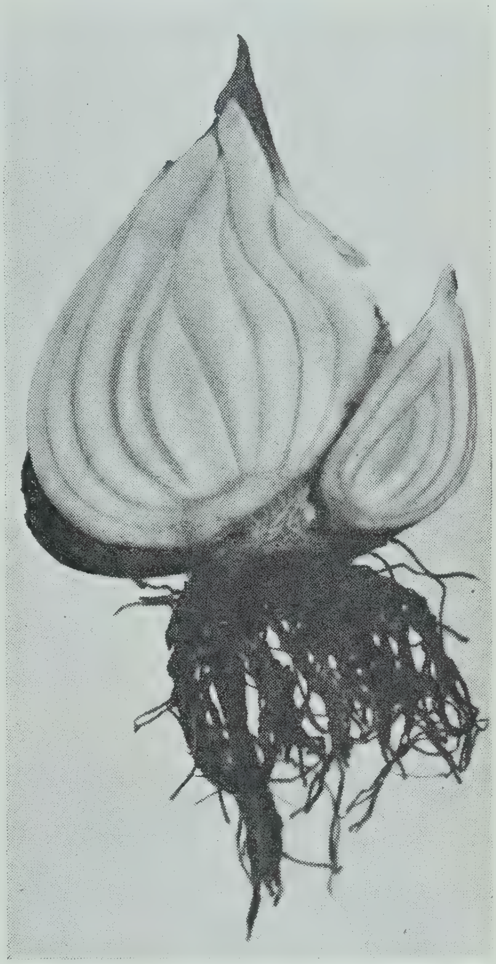

Fig. 30. A longitudinal section through a tunicate bulb of the tulip and likewise through its bulblet. Note that the bulblet has developed in the axil of one of the lower bulb scales. About natural size.

Buds develop in the axils of the scalelike leaves of all bulbs,

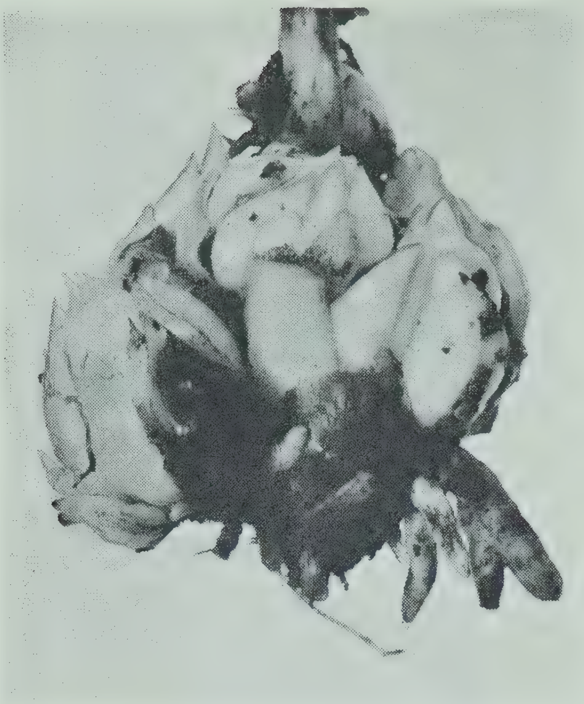

Fig. 31. A scaly bulb of the Easter lily (*Lilium longiflorum*) before it has fully matured. Note the stem of the plant at the top. Like many scaly bulbs this could be broken into several divisions and new plants grown from each one.

whether tunicated or scaly, just as they do in the axils of other leaves. At first they are minute structures, hardly visible to the naked eye. As they increase in size, however, they may acquire the general shape and appearance of the parent bulb. In other words, they may grow into nothing more nor less than little bulbs and are commonly called *bulblets* (Figure 31). If a scaly bulb, say of the Easter lily, is broken into several parts, each one of which has one or more of these attached bulblets, and the scales with their bulblets are planted in a suitable location, a new plant will be produced from each of the bulblets. Or the bulblets can simply be separated from the parent bulb, planted out where they can be given proper care, and in due time they will form full-sized bulbs. This may require one to six or seven years, depending on the kind of plant and conditions. It is, however, the method commonly employed in the propagation of most bulbous plants. In some species adventitious buds develop on the surface of the bulb scales (Figure 32); in many species, as the hyacinth (*Hyacinthus orientalis*), adventitious buds will form along the edges of cut or broken bud scales, and thus a single scale, when properly treated, may give rise

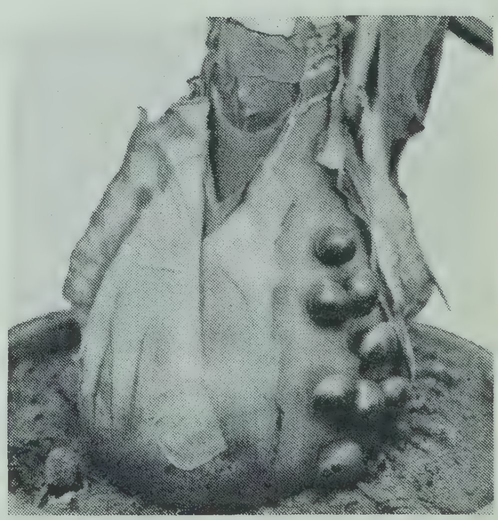

Fig. 32. Bulblets developing naturally from adventitious buds on the scale of a bulb of *Urginea scilla*, a greenhouse ornamental.

to a large number of bulblets. This makes possible the rapid propagation of new or valuable varieties.

When certain kinds of bulbous plants produce stems or flower stalks, the buds that develop above ground in the axils of their foliage leaves are often fleshy and bulblike in character. In structure they resemble closely the bulblets produced in, on, or around the bulbs of the same kinds of plants below ground. Because they are above-ground structures they are called *bulbels*, to distinguish them from bulblets. Figure 34 shows a plant of the tiger lily (*Lilium tigrinum*) just ready to come into flower and with small, compact scaly bulbels in the axils of its leaves. The bulbels of the Easter lily are clustered near the base of its stem. Bulbels are sometimes formed in the place of flowers on the flowering stalks of some bulbous plants, for example, the "top" onion shown in Figure 35 and some species of the *Agave*. A flower of one of the

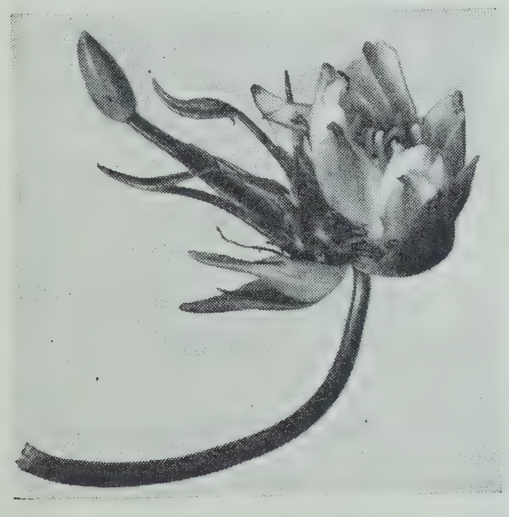

Fig. 33. A flower of one of the water lily (*Nymphaea*) hybrids showing a flower bud and bulbels developing in the axil of one of its sepals.

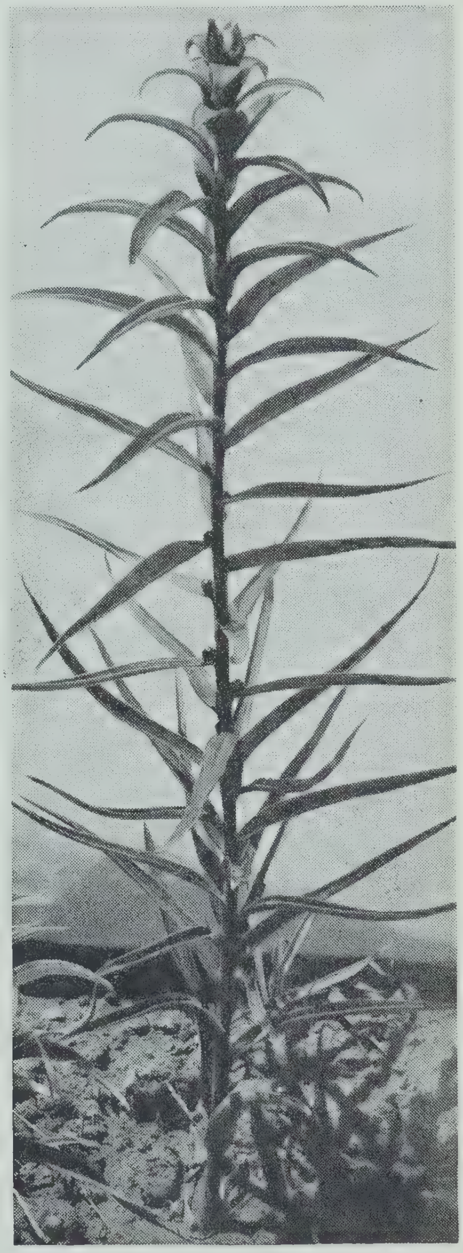

Fig. 34. Bulbels in the axils of the leaves on the median portion of a flowering stem of the tiger lily (*Lilium tigrinum*).

water-lily hybrids (*Nymphaea*) with both bulbels and a flower bud developing in the axil of one of its sepals is shown in Figure 33. Bulbels may be used in propagation, just as are bulblets.

CORMS

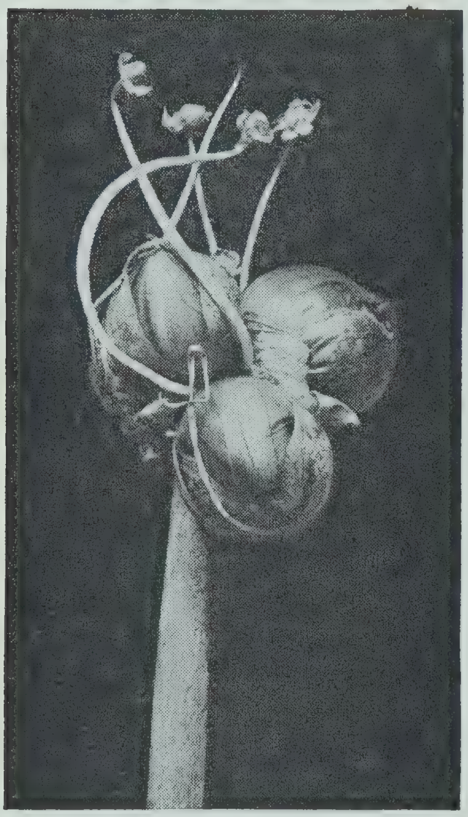

FIG. 35. The "flower" cluster of a *top* onion. Note that bulbels have developed in the place of flowers.

The corm is a specialized structure superficially resembling the bulb, but in the corm the bulk of the tissue consists of a short, relatively broad fleshy stem of only several nodes and internodes, and its leaves typically are not fleshy. If the leaf bases are fleshy, as in many of the orchids, the structure is perhaps as properly classified as a bulb instead of a corm, illustrating the fact that no sharp line can be drawn between the two structures. As a matter of fact, these intermediate cormlike, bulblike stem structures are often referred to as *solid bulbs* or *pseudo bulbs*. One is pictured in Figure 36. The gladiolus, crocus, and water chestnut (*Eleocharis tuberosa*) are examples of corm-producing plants. The buds in the axils of the leaves of corms usually develop into miniature daughter corms or *cormels*. These are used in the propagation of corm-producing plants, just as bulblets and bulbels are used in the propagation of bulbous plants. In many species, as the gladiolus, the parent corm dies and shrivels or decays before the end of the flowering season and is replaced by one of the cormels, which soon grows to full "flowering size." Besides this full-sized corm several smaller cormels are usually formed. The formation of large numbers of cormels from adventitious buds on the parent corms sometimes can be stimulated by artificially wounding the latter, and this is often done in their commercial propagation. This often takes the form of two or three vertical cuts across the base of the parent corm.

CROWNS

The term *crown*, as applied to plants, is used with a number of different meanings. The forester uses it to designate that portion of the top of a tree, as distinguished from its bole, which is perhaps ten or fifty or a hundred feet above the ground and has branches and leaves. More commonly the term *crown* is used to designate that part of the plant at the surface of the ground, including a short section of the stem just above the ground and the few inches of the stem just below ground to which the root system is attached. In the majority of cases this is of about the same diameter as the stem some distance above ground. In others, for example, the walnut or cocoanut palm, however, the crown portion is somewhat enlarged; in others, for example, the cypress (*Taxodium distichum*), it is considerably enlarged; in still others, for example, the greenhouse ornamental shown in Figure 36, it is enormously enlarged. In most of the so-called *stemless* plants, for example, the strawberry, rhubarb, and dandelion, that really are not stemless, the crown is about all there is to the stem and consists of little more than a pad or disk of more or less typical stem tissue whose diameter is perhaps many times its length or height. Roots grow freely from its under surface or the under surfaces of its very short horizontal branches, while the leaves develop from their nodes or perhaps from those of true, though perhaps very short, upright stems that grow out from some of its buds. Some of the buds, either terminal or lateral, on the short horizontal branches of the crown of these "stemless" plants, enlarge and become fleshy, more or less resembling bulbs in structure, except

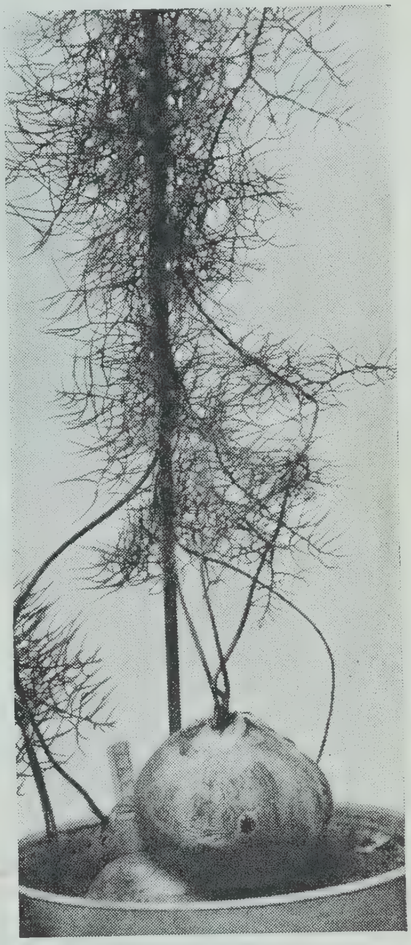

FIG. 36. This interesting conservatory plant (*Bowiea volubilis*), with an asparagus-like top, has a basal stem storage organ intermediate between a corm and a tunicate bulb.

that they are more firmly anchored to the parent structure. If left undisturbed, they provide the growing points for new rosettes of leaves, or upright stems or flower clusters, or short horizontal extensions of the parent crown, in other words, for further typical growth of the plant itself. There is, however, no clear division line between crowns and stems, especially compact, prostrate stems with short internodes. This is brought out in Figures 37 and 38. The creeping, above-ground structures of the *Aspidistra lurida*

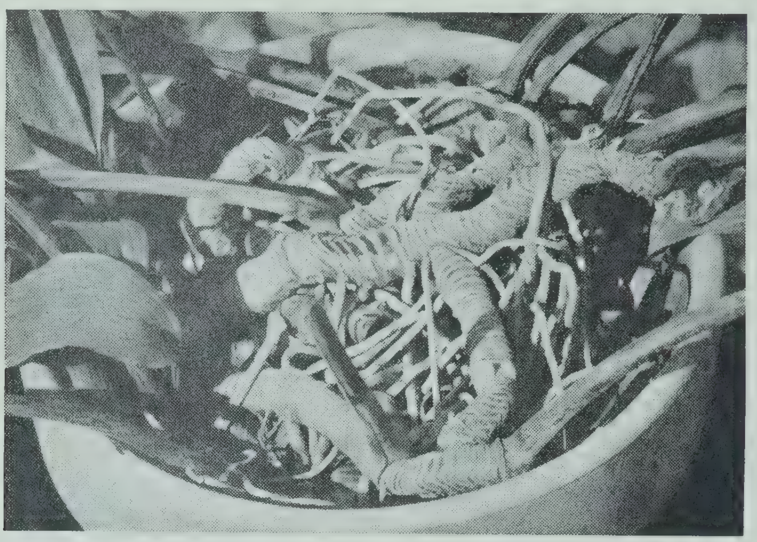

Fig. 37. The creeping short-jointed stem of a common house plant (*Aspidistra lurida*). By some these stems might be classified as crowns, but they grow above ground, though striking root freely. Compare with Figure 38.

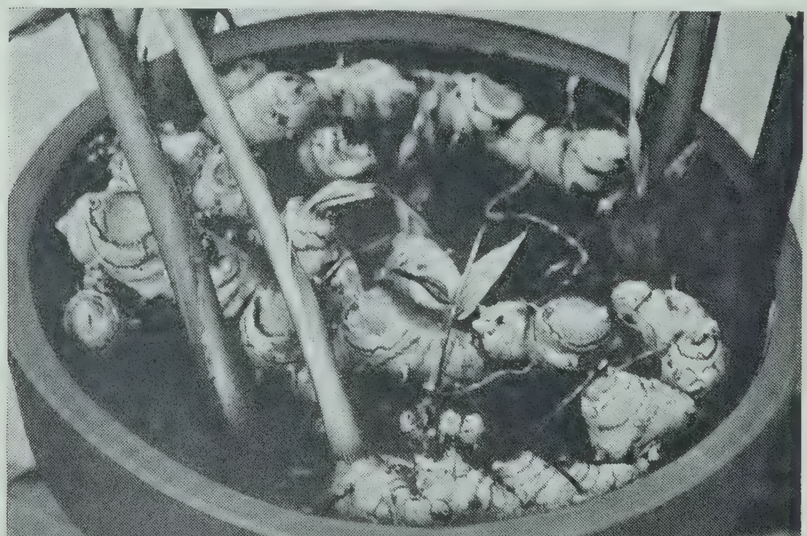

Fig. 38. Crowns of the ginger lily (*Hedychium coronarium*). They are a quarter to a third covered with soil and might, with almost equal propriety, be classed as thick fleshy rootstocks.

shown in Figure 37 should probably be classified as stems, though some might call them crowns. Their half-buried counterparts in the ginger lily (*Hedychium coronarium*), shown in Figure 38, undoubtedly classify as crowns. If broken or severed from the parent structure and placed under conditions suitable for growth, crowns or crown divisions will develop into new plants. This is a common method of propagating plants having this general habit of growth. In common parlance, these enlarged, individual fleshy buds of the crown are in turn called *crowns*, though more accurately they should be called *crown divisions*. Asparagus, rhubarb, the peony, banana, and many other commonly grown plants are readily propagated by crown division.

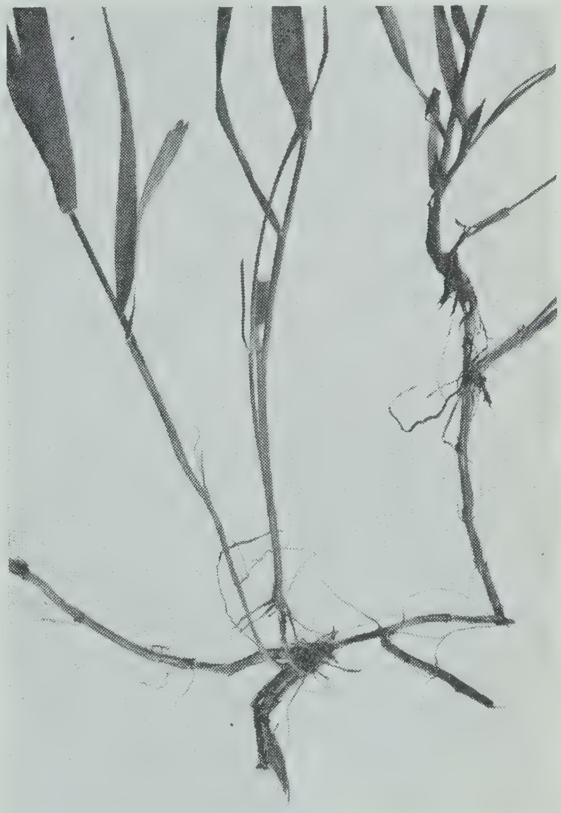

FIG. 39. Rootstock or rhizome of the quack grass (*Agropyron repens*). Note how it has rooted at the nodes and that upright shoots have arisen from some of them.

ROOTSTOCKS OR RHIZOMES

If the horizontally growing branches of crowns grow laterally through the soil some distance from the parent structure, and their internodes are somewhat longer than those of the typical "crown," we have what is termed a *rootstock* or *rhizome* (Figure 39). Normally roots develop from its nodes, and sometimes from its internodes, and shoots develop from the buds in the axils of its bractlike underground leaves. This type of growth, continued more or less indefinitely, enables a rootstock-producing plant to extend over and occupy a considerable area within a comparatively short time. If rootstocks are removed from their parent plants and cut or broken into a number of pieces, each one containing one or more nodes, each piece or division may be used for propagation purposes. Quack grass (Figure 39) and the Canada thistle are examples of plants whose spread and persistence are evidence of the effectiveness and reliability of rootstock propagation. Many herbaceous perennial ornamental plants are regularly propagated by means of their rootstocks. The horizontally growing branches of certain plants, for example, the iris, which are comparatively short, have short internodes, and grow about as much above as below ground, present structures more or less intermediate between typical crowns and rootstocks and illustrate the difficulty of drawing sharp lines between them.

TUBERS

A *tuber* is an underground stem or rootstock, a portion of which, usually some little distance out from the crown and involving several nodes and internodes, thickens and becomes fleshy (see Figure 40). In structure it more closely resembles the fleshy above-ground stem of the kohlrabi (Figure 41) or the typical corm than it does the normal above-ground stem, but differs from those structures in that it is formed on a more or less horizontal underground stem. Its so-called *eyes* are its nodes. The potato is one of our most common examples of a tuber-producing plant. Most tubers consist in large part of parenchymatous storage tissue. Either the whole tuber or pieces cut from it that contain one or more eyes

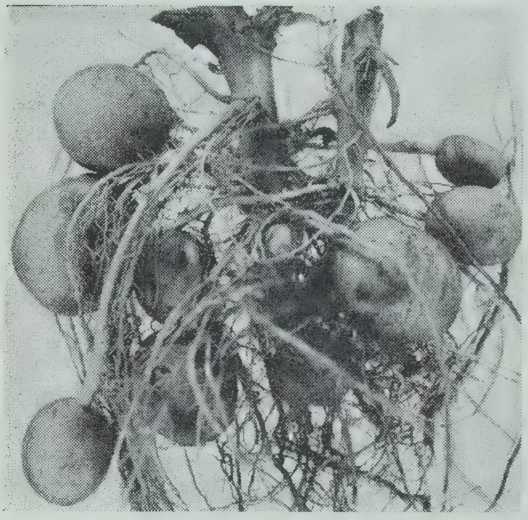

Fig. 40. Tubers of the potato, showing their manner of attachment to the bases of upright aerial stems. Note how much the tuber itself resembles the fleshy above-ground stem of the kohlrabi shown in Figure 41.

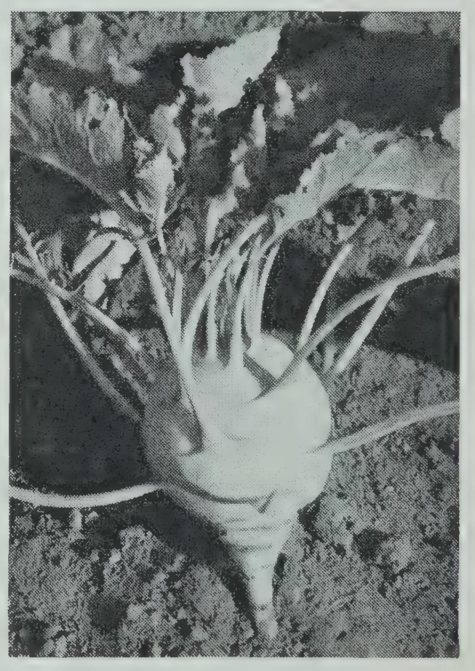

Fig. 41. The enlarged, fleshy stem of the kohlrabi. Note how much it resembles the tuber shown in Figure 40.

may be used for the propagation of tuber-bearing plants. Often confused with tubers are "tuberous" or fleshy roots, though the latter may be distinguished by the fact that they have no nodes. The fleshy underground organs of the dahlia and sweet potato are fleshy roots, instead of tubers. The tuberous root of the dahlia can be used for propagation only when it is removed from the parent plant with a "heel" of true stem tissue containing one or more nodes or "eyes." On the other hand, the fleshy root of the sweet potato can be used for propagation because it readily forms adventitious buds under conditions favorable for growth.

OFFSETS

An *offset* may be defined as a rather short, many-noded, rather slender, horizontal branch growing out from the crown, and bearing at its free end a large fleshy or semifleshy scaly bud or rosette of leaves. Sometimes, as in the *Haworthia fasciata* shown in Figure 42, the stem is very short and entirely above ground; sometimes, as in the American Turk's-cap lily (*Lilium superbum*) it is entirely below ground, and its terminal rosette of leaves as well; sometimes, as in the live-forever (*Sempervivum soboliferum*) shown in Figure 43, it is half covered with soil and half above ground.

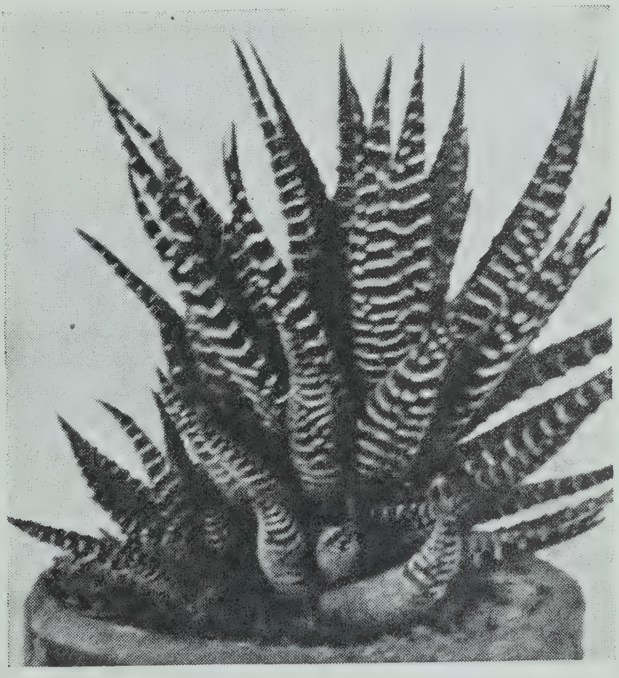

Fig. 42. A small potted plant of *Haworthia fasciata* showing a sessile, that is, a practically stemless, offset at its base on the left.

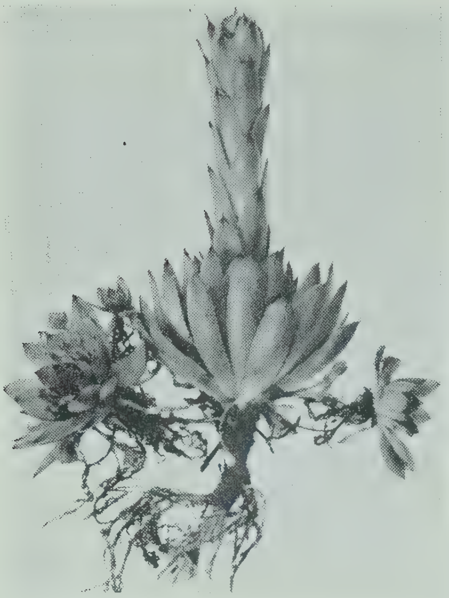

FIG. 43. A plant of live-forever (*Sempervivum soboliferum*) showing several offsets of different sizes. Note that these offsets have very slender stems that connect them with the parent crown.

The nodes of the horizontal stem usually bear rather inconspicuous, scalelike leaves, and the buds in their axils do not often grow out to form branches or rosettes like the one that it bears terminally (see Figure 43). However, it forms roots rather freely, and in some instances rosettes of leaves develop freely from its lateral buds. Under normal conditions of growth the offset furnishes a means by which the plant producing it spreads out to occupy more space (see Figure 44). If separated from the parent plant and planted under conditions favorable for growth the terminal rosette or offset strikes root readily and then leads an independent existence. The old-fashioned live-forever or *Sempervivum* is a good example of a common garden

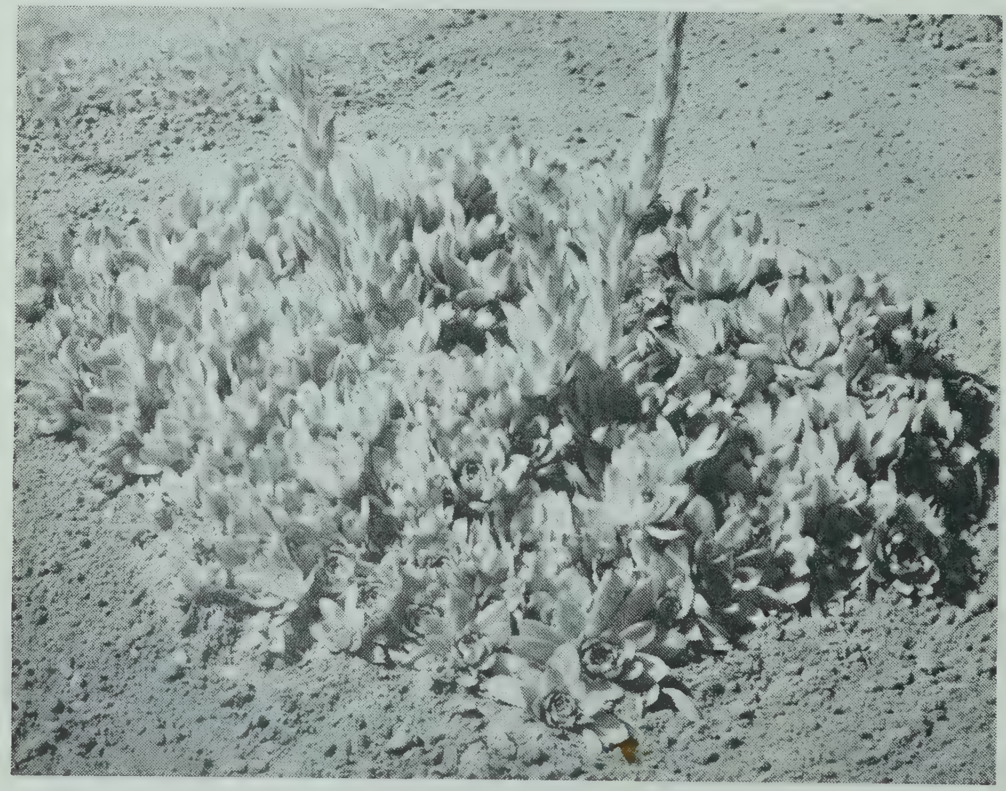

FIG. 44. An old clump of live-forever (*Sempervivum soboliferum*), showing its manner of spread by offsets.

plant that is regularly propagated by means of offsets. Many of the aloes, so popular as rock-garden and potted plants, are propagated by means of offsets.

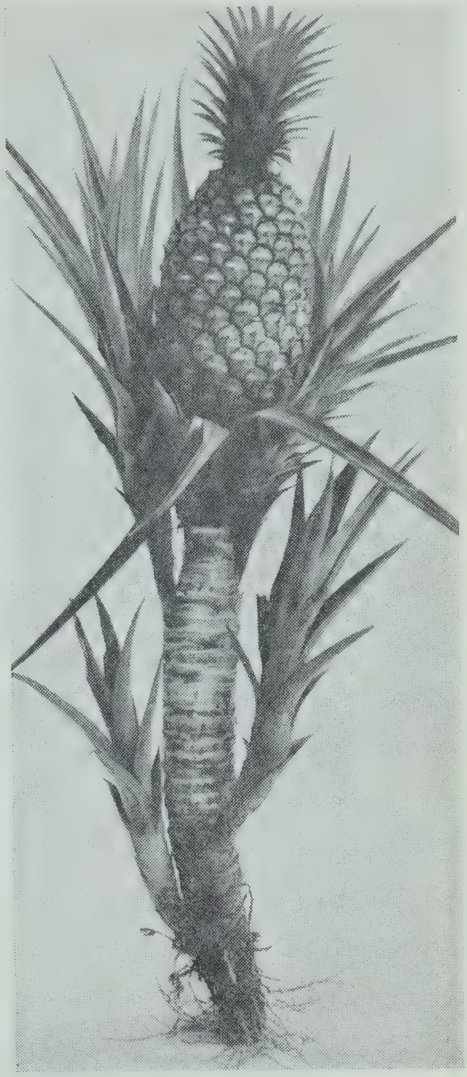

FIG. 45. A pineapple plant with most of its leaves removed to show stem and offset structures. The lowest offsets coming out from below ground level are called *ground suckers* or *ratoons;* those attached somewhat higher on the main stem are called *suckers;* those developing just below the fruit are known as *slips* or "*hapa*" *slips;* the terminal rosette is known as a *crown.* Courtesy of J. L. Collins, Hawaiian Pineapple Producers Cooperative Association.

No plant better illustrates offset structure, type, and function than does the pineapple (see Figure 45). A pineapple, during its first year in the field, consists of a compact rosette of long, narrow leaves. Sooner or later, depending on variety and conditions, one or more short underground branches grow out from its stem, turn up, and produce rosettes of leaves similar to that of the parent plant. These are typical offsets, called *ratoons* by the pineapple-grower. At about the same time above-ground branches spring from points several inches higher on the main stem. They are shorter than the ratoons, but similarly consist of rosettes of leaves like that of the parent plant. As a matter of fact, they are practically indistinguishable from the true offsets or ratoons. The pineapple-grower calls them *suckers,* though in point of origin they are more nearly comparable to the watersprouts of the deciduous fruit tree than to its true suckers. A little later, while a pineapple fruit is developing and maturing from the terminal inflorescence of the main stem, several rosettes are developing at its base, and by the time the pineapple is ready for harvest, they may be as large as some of the suckers and ratoons at the base of the same plant. They resemble the suckers and ratoons in structure and appearance and for all practical purposes may be considered offsets. The pineapple-grower calls them *slips*. Finally the pineapple fruit itself is topped or crowned by a rosette of leaves that likewise resembles the slips, suckers, and ratoons of the same plant. This offsetlike structure is called a *top*. After the pineapple fruit is harvested, one or more of the ratoons or suckers grow rapidly, blossom, and in due course of time mature fruits. This makes the so-called *ratoon crop*, though in reality a portion of this crop comes from suckers. A second and a third ratoon crop may be produced, though usually the pineapple-grower harvests only one ratoon crop and then starts a new plantation. As a rule, ratoon-produced fruits of the ratoon crop are somewhat smaller than those of the first or main crop, while sucker-produced fruits are smaller than those developing from ratoons. In a new plantation all four types of offsets are used. Of course, when the product goes to the fresh fruit trade, the *top* goes with the pineapple and is not available for propagation, but the *slips*, *suckers*, and *ratoons* are. However, he seldom uses the suckers, for they do not make as satisfactory plants as the slips and ratoons. Under conditions in which first or main crop fruits, say, of the Abaca variety, grown from slips will average from sixteen to twenty to the crate; those from ratoons will average eighteen to twenty-four; and those from suckers, twenty-two to thirty-two — in spite of the fact that all three kinds of offset at the time of planting are of about the same size and appearance. Should his crop be used for canning, and hence the *top* rosette be available for propagation, he prefers that to all the other offsets, for under similar growing conditions fruit grown from tops will average fourteen to twenty to the crate.

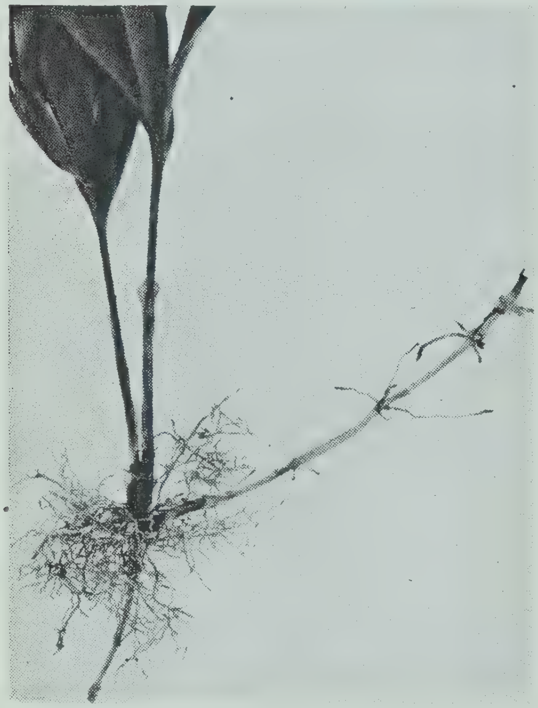

FIG. 46. A lily-of-the-valley (*Convallaria majalis*) plant with a rhizome that terminates in a rather large compact bud. This is called a pip.

When the terminal bud at the end of a short, rather slender rhizome or offset is rather compact and more or less resembles a tunicated bud or ordinary crown bud, it is sometimes called a *pip* (Figure 46). This is a specialized structure that is more or less intermediate between the crown on the one hand and a rootstock or an offset on the other. The lily of the valley (*Convallaria majalis*) is commonly propagated by means of pips.

RUNNERS

When a crown bud grows out to form a slender trailing stem with comparatively long internodes, and rooting takes place at some of the nodes accompanied by the development of a rosette or upright stem from the bud at the node, such a stem is called a *runner*. The strawberry is our most commonly grown example, though many ornamentals such as the Boston fern (*Nephrolepis exaltata* var. *bostoniensis*) and the pickaback (*Tolmiea menziesi*) shown in Figure 47, form runners freely. Many grasses produce runners that root freely at their nodes. Such plants spread naturally by means of their runners or may be propagated readily by separating rooted runners from the parent plants and setting them in a new location.

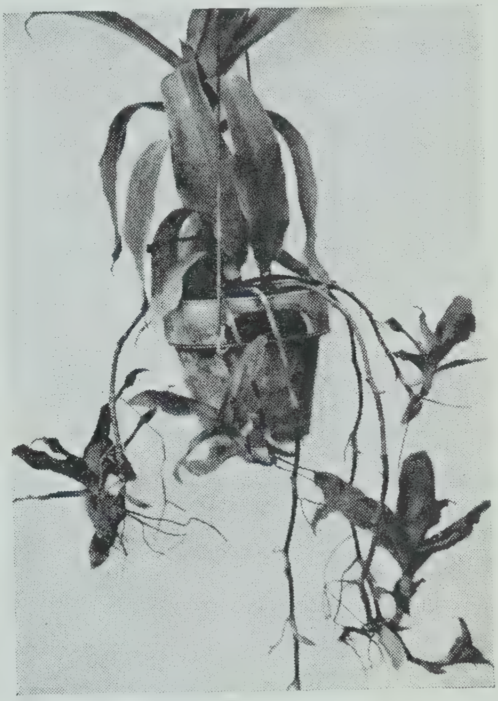

FIG. 47. A pot-grown plant of common pickaback or Moses-in-the-bulrushes (*Tolmiea menziesi*) that has formed a number of runners. Note the formation of aerial roots at their nodes.

STOLONS

Stolons differ from runners principally in that the stems are at first erect or semierect; then as they grow longer, they bend over with their weight; their tips finally touch the ground, and where they come in contact with the soil, they thicken and send out roots from their nodes. Soon after becoming anchored, a bud in the axil of a leaf in the vicinity of the roots develops into a shoot, and a new plant is thus formed. The golden bell (*Forsythia suspensa* var. *Fortunei*), dogwood (*Cornus stolonifera*), black raspberry, and dewberry regularly spread and are propagated by means of stolons. When the natural process is aided, sometimes by artificially bending the branch down and covering with soil, sometimes simply by covering with soil, the practice is called *layering* (*tip layering* or *common layering* depending on whether the tip or some other part of the branch is covered).

Many species of plants produce offshoots that are intermediate in type between the more or less distinctive types that have been described. Thus, that of the *Paradisea liliastrum*, a common greenhouse ornamental, bears some resemblance to an offset, some resemblance to a runner, and some to a stolon.

STOOLING AND TUBERING

The various types of offshoots that have just been described furnish a means for a rapid spread of the plants in question. They likewise furnish means for their artificial propagation when they are separated from the parent plant (as with bulblets, cormels, tubers, etc.) or the parent structures are *divided* (as with crowns). Little needs to be done by the grower or propagator except to make use of what nature provides, though, as has been mentioned, larger numbers of bulblets, cormels, etc. can usually be obtained by special treatment of the parent plant structures.

In the commercial propagation of a number of plants, use is made of growth processes and structures more or less related to the ones just described, by subjecting the plants to more artificial treatments. If their tops are cut off at the surface of the ground, the crowns, stumps, or roots of plants of many species sprout vigorously. If the sprouts arise from the roots, they come from adventitious buds; if from the crowns, they may spring either from adventitious or latent buds. If they arise some distance from the trunk, they are obviously from the roots and are called *suckers*. If they arise from the crown they are called *sprouts* and the whole group a *stool*. New roots often form rather freely from the lower nodes of suckers, and if a thin layer of soil is placed over the crown of a plant, roots will often develop from the nodes of the shoots that develop from it. When these shoots or suckers become well rooted, they can be separated from the parent roots or crowns and planted out. This method of propagation is *stooling* or *stool layering* and is commonly used with gooseberries, currants, and a number of ornamentals. The natural reproduction that takes place in this way in cut-over timberland is called *coppice*.

The shoots of some plants, for example, the blueberry, that have to penetrate a two- or three-inch layer of sand, soil, or peat placed over their crowns, often grow with very short internodes and scalelike leaves below the surface and then resume a normal type of growth when they reach the surface, resulting in a type of dimorphism. These scaly, usually upright, below-ground shoots or portions of shoots often resemble rhizomes more than they do aerial stems and strike root somewhat more freely than the normally growing portions of the same shoots. Propagation by means of these somewhat specialized or abnormal shoots is called *tubering*, and the shoots themselves are often called *tubers* or *tubered shoots*, though they bear very little resemblance to true tubers such as those of the potato shown in Figure 40; they are in reality a kind of artificially induced rhizome. Some tubered shoots of *Isoloma tydaea*, an attractive conservatory plant, are pictured in Figure 48. Some of these are especially interesting in that they show

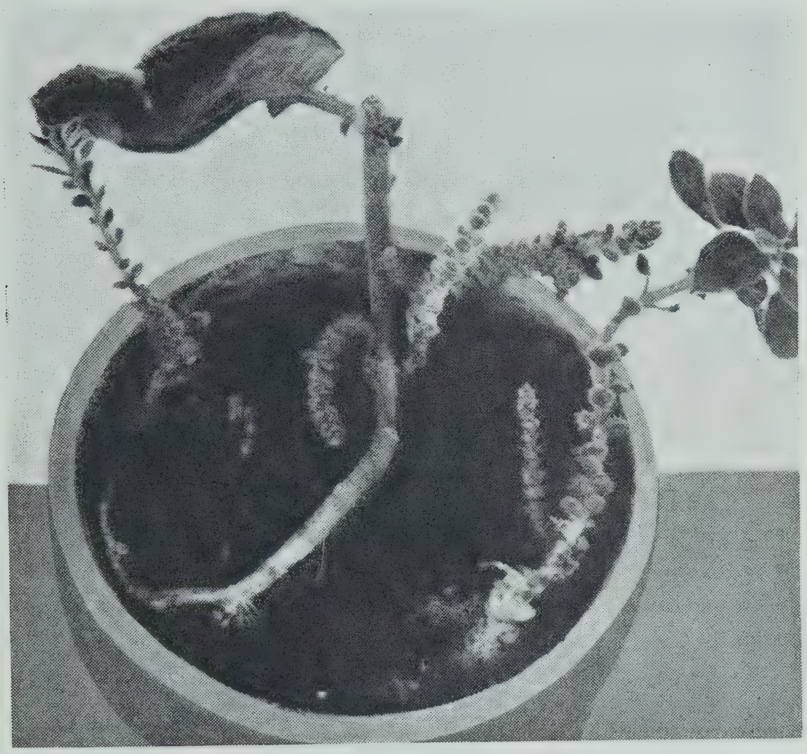

FIG. 48. "Tubered" shoots of *Isoloma tydaea*. Note the transition from the completely tubered condition shown by some of these shoots at the base to a normal aerial type of stem growth two or three inches higher. Ordinarily shoots do not become "tubered" unless forced to develop below the surface of the soil.

a gradation from a completely tubered condition at the base to a normal aerial type of stem two or three inches higher.

In a rather general way all of the plants that grow and spread by vegetative parts in one of the ways indicated — that is, by means of specialized buds, stems, or branches — are referred to as *bulbous* or *tuberous-rooted* plants. It is a type of growth that makes possible a seasonal life history in which a relatively short growing season alternates with a long resting period. The bulb or bulbel or cormel or tuber is stored with a larger amount of food than most seeds, and when conditions favorable for growth arrive, a very rapid and sizable initial growth can be made. This large vegetative growth in turn makes possible a rapid accumulation of food material that can be stored in the bulb or tuber or corresponding part until the next season. Many bulbous and tuberous-rooted plants come originally from desert or other sections where the growing season is short, and very rapid growth is imperative if a top growth of any considerable size is produced before the season ends.

PROBLEMS

1. Which would you expect to spread more widely and quickly: a newly introduced weed that propagates only by means of seeds or one that propagates only by means of rootstocks? Why?

2. Which would you expect to be the most difficult to control within a given area or on a certain farm: a weed that propagates only by means of seeds or one that propagates only by means of rootstocks? Why?

3. **Make drawings to illustrate the structure of a cyclamen corm, a kohl rabi stem, and a potato tuber, and then frame a statement that will differentiate between corm, stem, and tuber structures.**

4. Is the difference between the "sprout" of Brussels sprouts and the bulbel of top onions one in structure or function? Explain.

5. Trees, shrubs, and woody vines seldom form specialized buds and stems such as bulbs, corms, rhizomes, etc. How do you account for this?

CHAPTER V

TEMPERATURE RELATIONS OF PLANTS

LIMITING factors for growth processes of all kinds depend on the presence or existence of certain conditions — certain ranges of temperature, the presence of certain amounts and intensities of light, a supply of moisture, and certain nutrients. If all of these conditioning factors are at their optimum, relatively rapid growth is possible; otherwise it is retarded or perhaps altogether stopped. However, the conditions of temperature or moisture supply that are most favorable for the growth of one kind of plant or for one growth process may not be most favorable for that of some other plant or other growth process. If the plant-grower knows how these several factors limit development — what are the minimum, optimum, and maximum light, temperature, and moisture conditions for different plants and different plant functions and processes — he can either try to provide the best possible conditions or to secure the maximum development possible under the existing conditions through selection of adapted plants or varieties.

TEMPERATURE AS A LIMITING FACTOR

At no time is any plant or any plant organ, tissue, or cell free from or independent of the influence of temperature. It constantly and more or less directly influences all of the growth processes.

Several features of temperature as it influences growth, or perhaps more accurately, several different temperature responses of plants will be briefly discussed here.

MINIMUM TEMPERATURES

As everyone knows, plants cease to grow at the onset of sufficiently cold weather, though just how cold it must become in order for them to stop growing varies with the kind of plant and with conditions. The freezing point of water (32° F.) is popularly regarded as the point below which growth is suspended and above which it proceeds. The situation, however, is not so simple. Although the seeds of many hardy or cool-weather plants — for example, wheat, oats, radish — will germinate slowly at temperatures slightly above freezing and the plants that they produce will grow slowly at those same temperatures, seeds of warm-season crops — such as tomatoes, cucumbers, and corn — require considerably higher temperatures for germination. Furthermore, the plants of these same crops require higher temperatures for growth than those of the cool-season crops. Actively growing plants of warm-season crops may be killed by a few hours' or perhaps a few minutes' exposure to a temperature one or two degrees below the freezing point. Plants of cabbage or peas may withstand many hours of freezing at 25° to 28° F. Well-cured seeds of some of the most tender plants may withstand long exposures to temperatures many degrees below the freezing point. So the minimum temperature that one plant endures may be much lower than that which another will tolerate, and different parts of the same plant, organ, or tissue may vary greatly in the minimum temperature that they will endure, depending on season of year and condition of maturity. Thus, a raspberry shoot that might be killed by a temperature of 28° F. in July may be uninjured by a temperature of −20° F. in midwinter, because, as we say, it has matured or ripened up or become hardened in the meantime.

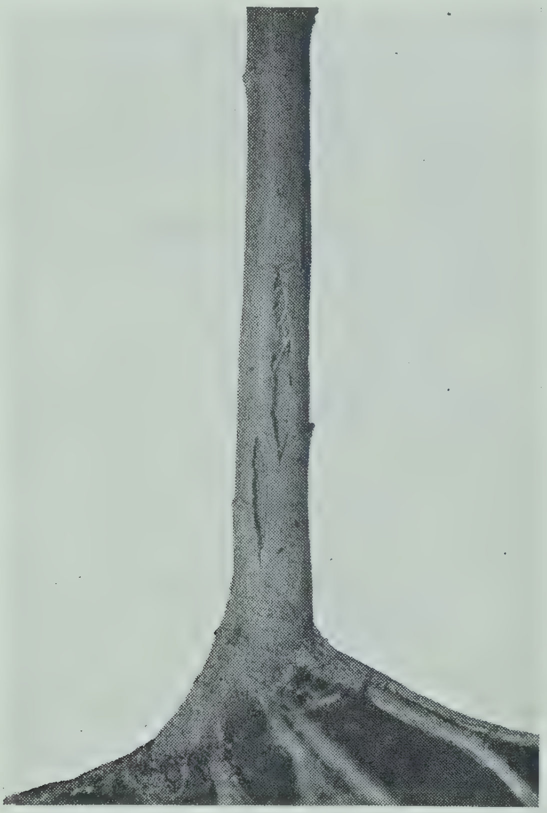

FIG. 49. Bark splitting on the trunk of a young fruit tree due to a sharp fall freeze. Overvigorous growth, especially late in the season, predisposes trees to this form of winter injury.

Moreover, as between different parts of the same plant at any one time there may be marked differences in hardiness. The roots of most plants whose tops become acclimatized to low winter temperatures likewise acquire some resistance to cold, but much less than that of the above-ground parts. Thus, 15° to 20° F. is the minimum soil temperature for apple roots in winter, while the tops will survive −15° to −30° F., depending on variety and condition. Flower buds of most species and varieties are killed before the leaf buds, most peach flower buds, for instance, being killed by −12° to −16° F., while their leaf buds commonly survive −16° to −22° F. Shoot growth produced late in the season is more tender than that produced earlier, the terminal portions of the canes of bramble fruits commonly killing back a few inches or more while the basal and median portions remain uninjured. Wood and bark in the crowns and crotches, particularly sharp-angled crotches, of many trees apparently mature more slowly than bark and wood of trunk and branches and consequently are more subject to winter injury. Indeed, a number of the different forms of winter injury, of which bark and trunk splitting (Figure 49), and crown (Figure 50) and crotch injury are

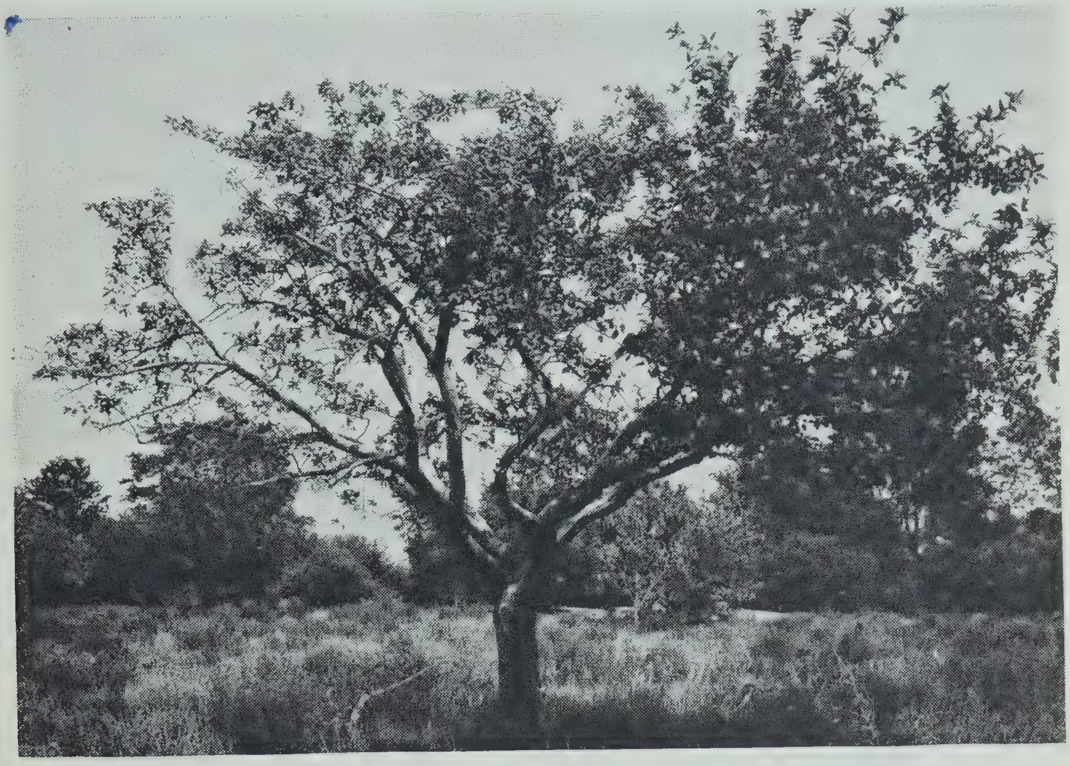

FIG. 50. An apple tree that shows the effects of crown injury. Killing of bark and cambium on one side at the crown has restricted the flow of water, nutrients, and food materials on that side, and branches above the injured area are showing dieback.

some of the most common, get their specific names from the organs or tissues that are affected. Sometimes crotch injury due to low winter temperature is called *frost canker.* A good example of frost canker on peach is shown in Figure 51.

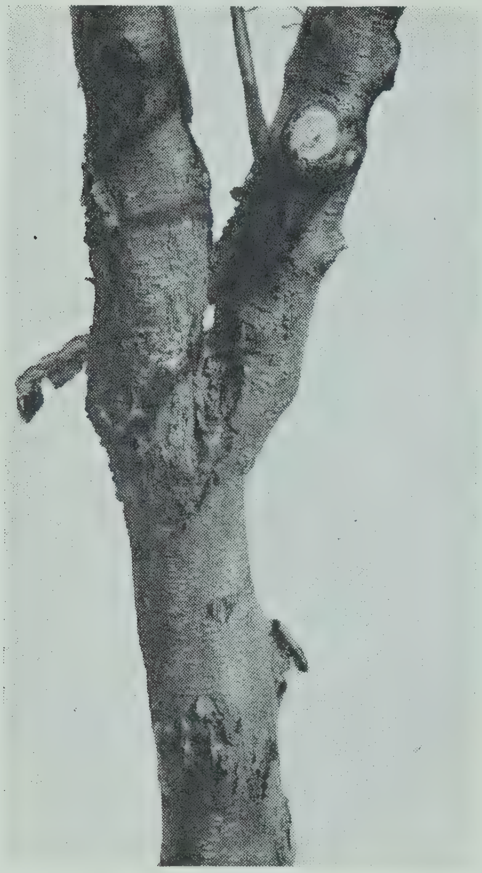

FIG. 51. Framework of a peach tree showing killing of bark and cambium in the crotches, due to low temperatures in fall and early winter. Injuries of this kind are sometimes called *frost cankers.*

In just what the maturing, ripening, or hardening process consists it is difficult to say. Apparently, several processes and functions of the plant are involved. For one thing, well-matured or hardened tissue is somewhat less succulent than less mature tissue of the same kind. Thus, the shoots of a raspberry or apple may contain 55 per cent water in late summer and early fall, when they are tender to cold, but only 48 to 50 per cent water in late November when they will withstand severe freezing. Rapidly grown, unhardened, greenhouse-raised, cabbage plants may contain only 10 per cent dry matter; ten days later when well hardened they may contain 15 per cent dry matter. This suggests that hardiness to cold is in some way connected with the water content of the tissues. However, it is not entirely a matter of dryness for a tomato or melon plant that will be killed by a temperature of 30° to 32° F. may contain less water than a cabbage that is not injured by a temperature of 20° to 22° F. Apparently, more depends on the form or condition in which the water is held in the plant tissue than on its total amount or percentage.

Some of the water of plant tissue is "free" — that is, water in which very little or nothing is dissolved. Water of this classification is found in the form of thin films surrounding the cells and lining the intercellular cavities. The water within the cells occurs in two forms: (1) as water in which various substances are held in solution, spoken of as *osmotically held*, and (2) as "bound" water, that is, combined with some of the chemical constituents of the cell to form a kind of jellylike, semisolid mass. This is often referred to as *colloidally held* water. Only the free water freezes at 32° F. or slightly below; the osmotically held water freezes at somewhat lower temperatures, and the colloidally held water at still lower temperatures. The larger the percentage of water held in the colloidal form the slower is the freezing, the less water is frozen at a given temperature, and the greater is the degree of resistance to cold. Ripening, maturing, or hardening processes effect an increase in the chemical substances within the cell that holds water osmotically and colloidally, thus keep it from freezing (or, more accurately, keep a larger proportion of it from freezing at a given temperature), and thus increase hardiness. These processes are especially effective if they increase the colloidal, as contrasted with the osmotically active, constituents of the cell. Apparently the reason tomato and melon plants cannot be materially hardened by the processes or treatments that effect marked hardening in cabbage or celery plants is that they have little effect in increasing the quantity of colloidal constituents.

In general, treatments which check cell division and increase in cell size but do not at the same time stop the manufacture of foods by the leaves, result in an accumulation of food materials within the cells and tissues in question and increase hardiness. Such treatments include the withholding of water and nutrients, the gradual lowering of temperature and exposure to strong sunlight — all measures employed by the gardener in producing strong stocky plants for transplanting from greenhouse or hotbed to the field in the spring. Nature effects a hardening or maturing of the tops of both woody and herbaceous plants in the fall through the onset of cooler weather. A dry fall aids and hastens the process; a wet fall retards it. Similarly, bright sunny weather aids and dull cloudy weather retards it.

Also to be noted are differences in the minimum temperatures for different processes within the same plant. Thus, some chemical changes, as the change from starch to sugar, may go on within the trunk and branches of a tree at a temperature of − 15° F. when cell division and increase in bulk would not take place unless the temperature rose to 40° F. Seeds of the annual larkspur

(*Delphinium ajacis*) germinate well at low temperatures but very poorly a little later when the soil becomes warm. On the other hand, seed of the cockscomb (*Celosia cristata*) remains in the ground all winter and seldom germinates until the arrival of warm weather. Celery seed germinates at low temperatures (35° to 45° F.), and the young plants grow slowly while it is cool (40° to 55° F.). However, let the plant be subjected to these comparatively low temperatures, even for a very short period, after it has once grown more rapidly in a temperature of 60° F. or above, and some change is effected or process modified that results in "bolting" later in the season, instead of the normal type of vegetative growth. Minimum temperature, therefore, is seen to be something which varies greatly with kind of plant, plant process, plant organ or tissue, and with conditions both of the plant and its environment.

It is important for the grower to know what may be expected in the way of minimum temperatures where he plans to grow his crop and likewise approximately the minimum temperatures that the plants will withstand at different stages in their growth. If the minimum winter temperature to be expected is 0° F., he should know that, though it is entirely safe to grow apples or pears or peaches, the attempted culture of oranges or lemons or Japanese persimmons is likely to prove disastrous. If the minimum temperature to be expected is 26° F., he will know that, though the orange and grapefruit will be safe risks, the avocado and mango will not. If the minimum temperature to be expected is − 25° F., the apple-grower should know that his variety list should be limited to such varieties as Duchess, Wealthy, McIntosh, and Northwestern Greening and should not include such kinds as Baldwin, King, and Rhode Island Greening.

MAXIMUM TEMPERATURES

Just as there is a minimum temperature which each plant or plant organ will tolerate and survive, but below which it is destroyed, so there is a maximum temperature that it will endure. This, too, varies with the kind of plant and with conditions. Though the absolute maximum for living protoplasm is close to the boiling point (found in certain single-celled or simple organisms inhabiting hot springs), for most of the higher plants the lethal point lies somewhere between 110° and 130° F. (*shade*, not *sun*, temperatures). A number of the growth processes are much retarded at temperatures considerably under those points. Indeed, it is usually temperatures substantially under the actual lethal points that are considered the maximal for the plants in question, for under actual growing conditions these are the temperatures that set limits to the culture of the plant. Thus, it is impracticable to attempt to raise head lettuce where the temperature in midday rises above 80° F. in the shade, even though a temperature of 100° F. does not actually kill the plants. An exposure of the plants of most varieties for only a few hours to a temperature above 80° F. leads to tipburn, bolting, and the prompt deterioration of the heads. Some of these high-temperature effects on head lettuce are shown in Figures 52 and 53. Tomato flowers fail to set fruit when the shade temperature rises to 95° and 100° F. or above (see Figure 54), and the fruits that may have set earlier and are partially grown are likely to develop "blossom-end rot" (see Figure 55) during periods of such high temperatures. The fact that some of these disorders are probably due as much to temporary water deficits, to the inability of the water-conducting system of the plant to keep the parts in question adequately supplied with water, as to high temperature does not make high temperature any less responsible for setting the limit to the successful culture and fruiting of the plant.

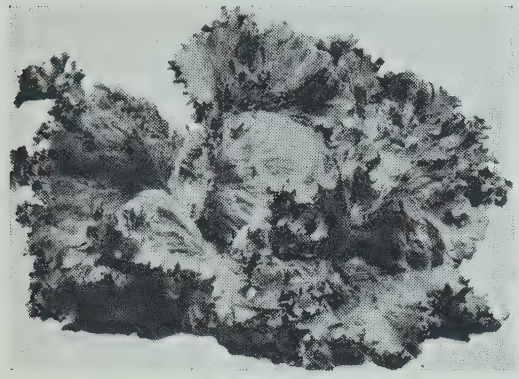

FIG. 52. A normal head of lettuce. Compare with Figure 53.

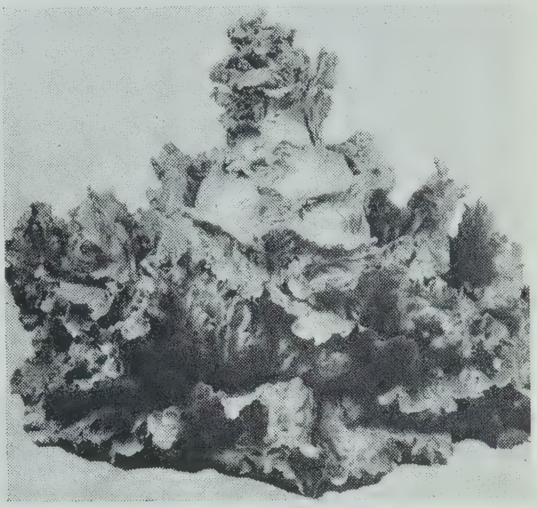

FIG. 53. A head of lettuce starting to "bolt," that is, to develop a flower stalk, as a result of exposure for a couple of days to a temperature above 80° F.

It is just as important for the producer to know that most head-lettuce varieties tipburn and bolt where day temperature in the shade exceeds 80° F. even very temporarily and that sweet corn quickly loses its sweetness when the temperature exceeds 90° or 95° F., as it is that the red raspberry grows well in few areas south of the Mason-Dixon line because of high summer temperature. Similarly, it is as important for the producer to know that if nasturtiums, potatoes, and cabbage are to be grown in Florida, they must be grown as winter crops, as it is for the orange-grower to know that 22° to 24° F. is his critical minimum temperature range.

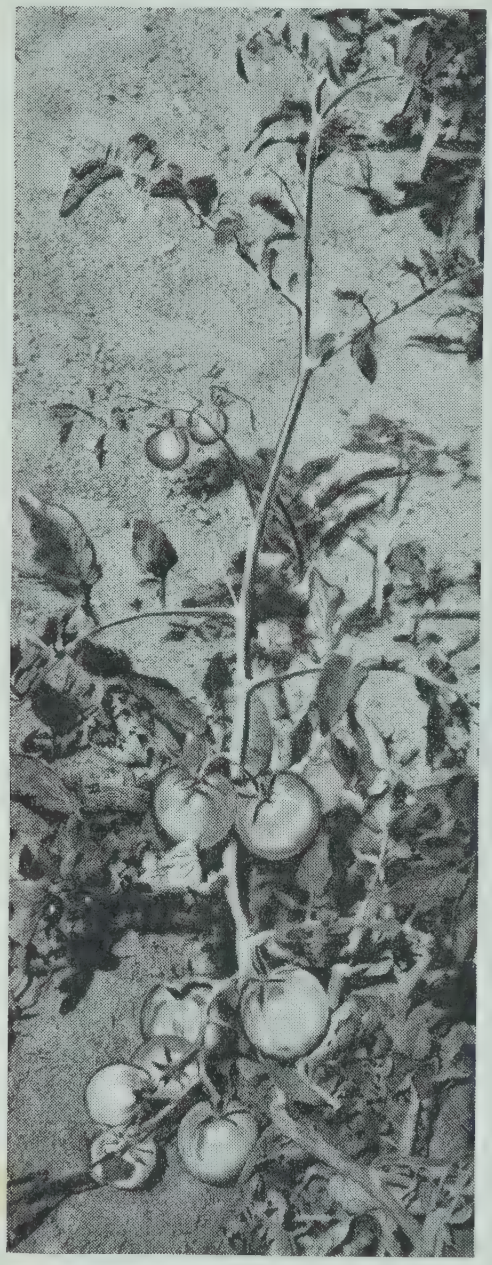

FIG. 54. A branch of a tomato vine showing the influence of high temperature and drought on fruit setting. The lower flower clusters set well, but those formed later when the temperature ranged from 80° to 90° F. daily set poorly.

MEAN TEMPERATURES

Somewhere between the minimum and maximum temperatures that any plant will endure is a point, usually closer to the maximum than to the minimum, at which the plant grows best. This is known as its *optimum temperature*. Thus, it has been established that the optimum night temperature for the carnation is about 55° F., its optimum day (full sunlight) temperature about 72° F. Corresponding temperatures for the rose are 70° and 90° F. Orchids belonging to such genera as *Dendrobium* and *Phalaenopsis* should be grown in greenhouses in which night temperatures do not fall below 60° to 70° F.; night temperatures for *Odontoglossum* may go as low as 50° F. Somewhat higher temperatures may be maintained with most greenhouse crops when days are bright and sunny and the days are long than during periods of cloudy weather and short days. Flower buds are formed in greater numbers by some of the azaleas and rhododendrons (*Azalea japonica*, *A. hinodegiri*, *Rhododendron carolinianum* and *R. mucronatum*) at 75° to 80° F. than at 50° to 60° F. Cabbage and cauliflower grow best where the mean daily shade temperatures range from 50° to 60° F.; casaba melons reach perfection only where the mean shade temperature is above 70° F. The Baldwin and McIntosh apples develop best in a mean temperature of 59° to 60° F.; to attain a comparable degree of perfection Winesap and York Imperial apples require a mean growing-season temperature six or seven degrees higher, while Jonathan and Rome occupy an intermediate position. Bartlett, Anjou, Bosc, Winter Nelis, and a number of other pear varieties attain higher dessert quality, longer keeping, and better shipping quality — in brief, a higher degree of perfection — where the mean growing-season temperature is 68° to 70° F. than where it is five to ten degrees lower. However, the pear blight organism is far more active and difficult to control at the higher than at the lower temperature. Therefore, most pears of these varieties are grown in areas whose temperatures are intermediate between these two extremes. The highest-quality sweet corn is produced and processed in Maine, not because the corn plant thrives better in the soils of Maine than in those of Illinois and Iowa, but because the lower mean temperature during the maturing and harvesting season retards respiration and the change of sugar into starch, and the half-ripe kernels reflect this condition. It is for essentially the same reason — that is, retarded respiration — that the cool

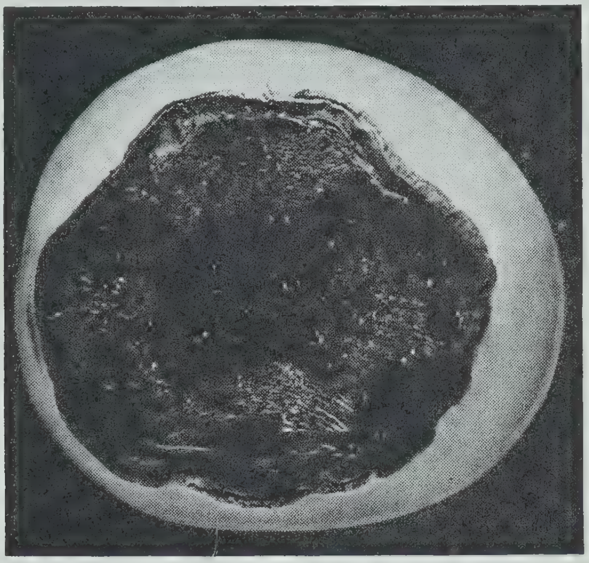

FIG. 55. Blossom-end rot of the tomato, due to high temperature and water deficit in midsummer.

autumn nights of northern latitudes and high altitudes, coupled with bright sunny days, are favorable to the development of high color on apples. Failure to recognize the practical limitations placed upon the culture of many kinds and varieties of plants by mean growing-season temperatures has led to countless failures and disappointments.

The New England fruit-grower who visits a fair and sees and tastes some Missouri- or Washington-grown Delicious apples and then, knowing that he can grow the McIntosh very successfully in his location and believing that "apples are apples," decides to plant Delicious in his own orchard would probably never think of trying to grow a variety of corn adapted to southern Illinois or Missouri. Yet he is attempting something strictly comparable. He can grow Delicious apple trees and mature Delicious apples, but they will be a far different product than the Delicious apples of the Ozarks or the Wenatchee valley. It is not just accident that the highest-quality sweet corn and peas come from the northern states and the highest-quality cantaloupes and casaba melons from certain sections of Colorado, Utah, and California; it is due primarily to influence of mean growing-season temperatures on the plants in question.

CLASSIFICATION OF CROP PLANTS BASED ON TEMPERATURE RELATIONS

There are two common, though rather loose, classifications of crop plants based on their temperature requirements and their responses to temperature. One of these classifications groups them as *temperate-*, *subtropical-*, and *tropical-zone* plants. Temperate-zone plants, as the term indicates, are those commonly found in the temperate and colder regions, plants which will endure considerable cold while in a dormant state. Tropical plants are those unable to endure freezing temperatures; some (for example, certain orchids) are severely injured by temperatures somewhat above the freezing point. Severe defoliation of the croton (*Codiaeum variegatum*), is caused by a drop in the temperature to 34° to 36° F. on several successive nights. Subtropical plants are intermediate in character, usually surviving frosts and mild freezing. No sharp line can be drawn between these several groups. By common consent, the banana, mango, date palm, coffee, and avocado are classed with the tropical group, even though they will sometimes endure light frost without apparent injury. The orange, lemon, grapefruit, fig, and pomegranate, which, when in a semidormant condition, will withstand minimum temperatures of 24° F. to 20° F. or even a little lower, are grouped with the subtropical plants. Plants whose vegetative parts, either those above or those below ground, are able to endure temperatures below that point are classed as temperate-zone vegetation, though there is a wide range in their hardiness; some, as the gooseberry and Tartarian bush honeysuckle (*Lonicera tartarica*), are very hardy, and others, as the Japanese persimmon (*Diospyros kaki*) and crape myrtle (*Lagerstroemia indica*), are little hardier than those of the subtropic group.

This does not mean that temperate-zone plants never thrive in the tropics or that subtropical or tropical plants never grow in the temperate zone. Maize, the tomato and potato, tobacco and buckwheat, are frost tender and killed by temperatures only slightly below the freezing point, just as are the date palm and the banana. Being annuals, however, and able to complete growth within a comparatively short period, many of their varieties may be grown as far north as 45° or 46° latitude during the hot summers that prevail in many northern areas. They are, nevertheless, essentially tropical or subtropical plants — in fact, they are just as truly tropical as is the *Coleus*, castor-oil bean (*Ricinus communis*), or *Canna* which are regularly grown in greenhouse conservatories. A plant like the common garden asparagus whose above-ground parts are killed by light frost but whose crowns and roots withstand severe freezing is classed with the temperate-zone group. Some plants, like the strawberry, grow well throughout a very wide temperature range.

A second convenient classification of plants based on their temperature relations places them in cool-season or warm-season groups. The cool-season group includes such vegetables as peas, spinach, radishes, and carrots and such ornamentals as pansies, phlox, and chrysanthemums, which can be seeded relatively early, will endure severe frosts and mild freezes, and generally thrive best in cool weather. The warm-season group includes such vegetables as eggplant, sweet potato, cucumber, melons, and beans and such ornamentals as the dahlia, zinnia, cosmos (*Cosmos bipinnatus*), and morning-glory (*Ipomoea hederacea*). Plants of the latter group are seeded or planted out after danger of frost is past, and they thrive best at relatively high growing-season temperatures.

Their above-ground parts are usually killed by the first fall frosts. Both groups include annuals, biennials, and perennials. The crops grown in the cool midsummer of the North are raised as spring or fall crops in the central states, in midwinter in the South; some of the warm-season crops of the North are midwinter crops in the tropics. Though woody plants that survive the cold of temperate-zone winters are not so commonly classified as cool season or warm season in character, in reality they may be so grouped. Thus, the gooseberry and currant are not only hardy to severe winter cold, but they thrive only in the low growing-season temperatures of northern latitudes or high altitudes. On the other hand, the Japanese persimmon and scuppernong grape (*Vitis rotundifolia*), though resistant to comparatively low winter temperature, demand relatively long and warm summers.

LENGTH OF GROWING SEASON

Closely correlated with the influence of mean growing-season temperature on plant growth is that of the length of growing season — generally considered as the period between the last killing frost in spring and the first killing frost in autumn. Many sections are characterized by mean temperatures that are ideal for the development of certain crop plants but they are too short in duration for the plants in question to complete their seasonal life cycle and mature properly. Thus, the English walnut, which is an important crop in parts of France and even in some parts of England, is grown in sections of those countries with mean growing-season temperatuers comparable to those in parts of New York and Michigan, but for the most part the shorter growing seasons in these two states do not permit proper maturity of either nuts or wood. The pecan is native to many parts of Missouri, Arkansas, and Oklahoma with mean growing-season temperatures comparable to those of South Dakota and Wisconsin, but it is not found in the latter states because their summers are too short for it to mature properly. Corn is grown with equal success in Missouri and Minnesota, in Georgia and Michigan, but the varieties are different — the long-season kinds grown in the more southern states being not at all suited to culture in the northern short-season states. The summers of Sitka, Alaska, are warm enough to raise Cuthbert raspberries and Duchess apples, and the winters are no more severe than those of many northern states where these same varieties are raised successfully, but the fruits seldom mature because Alaska's summer season is too short.

INDIRECT TEMPERATURE INFLUENCES

Certain indirect influences of temperature on plant growth and distribution are hardly less important than the more direct effects upon the plants themselves. Among these is its influence on the prevalence of certain insects, fungi, bacteria, and other parasites, for they, as well as the host plants, thrive in or are retarded by favorable and unfavorable temperatures. Temperature, as well as other conditions of climate, in the southeastern fifth of the United States, is favorable for the growth of many varieties of plums and cherries; however, it is even more favorable for the spread and development of the brown rot fungus, and so, though it is easy to grow the cherry and plum trees, it is difficult to ripen their fruits; consequently, they are little grown in that general area. The same statement holds for the many varieties of the European pear and the pear blight organism, a bacterial disease. Heavy infestation of the soil with nematodes, worms of almost microscopic size that cause knotting and deformation and death of the roots (see Figure 167), limits the practical culture of many vegetable and flower crops to sections where freezing of the soil holds this parasite in check. Largely because of favorable temperature conditions the New Jersey apple-grower has to combat three or four broods of codling moth each season, while the New England grower has only two broods, and in some sections of western Montana where the nights are too cold for the moths to breed and lay eggs, there are no codling moths to contend with. This makes a difference in the number of spray applications necessary in the several sections and consequently in production costs.

THE REST PERIOD

Mention has already been made of the fact that growth as a whole and likewise the different growth processes are in many instances characterized by periodicity. That is, growth may proceed rapidly for a while, then at a slower pace, and finally come to an apparent stop. When a plant or a plant part is at an apparent standstill, we say it is *dormant* or in a *period of dormancy*, and when this period of dormancy is so deep or profound that even though the plant is again surrounded by conditions favorable for the resumption of growth, it remains dormant, we say it is in a *resting period.* Many plants begin to enter a resting period upon or shortly after ceasing active growth and remain in it for variable periods of time. Others apparently do not have such resting periods.

Under natural conditions — at least, with most temperate-zone plants that are characterized by rest periods — low temperature is the agency which ends or "breaks" the rest period. With some plants a single exposure, perhaps for only a few hours or even minutes to a temperature of, say, 15° F. or 10° F. serves to break the rest period, and such an exposure will be followed promptly by vigorous resumption of growth whenever conditions are provided that make such resumption possible. For instance, lily of the valley (*Convallaria majalis*) and bleeding heart (*Dicentra spectabilis*) will not flower until after they have been subjected to a short period of hard freezing. In other instances a much longer exposure to a higher, but nevertheless cool, temperature has the same effect. Thus, it has been determined that about 1,000 hours of exposure to a temperature of 40° F. will break the rest period of the peach tree. Sections where the winters are too mild to provide that much cool temperature cannot grow peaches because their rest period will remain unbroken at the onset of warmer spring weather, though new varieties are being developed to extend southward the areas where the peach may be grown successfully. These new varieties require less cold to break their rest period than do the older varieties formerly available. In many instances the southern limits for the practical culture of fruits are set by mean or minimum winter temperatures, while in others they are set by maximum or mean summer temperatures. On the other hand, somewhat further north early breaking of the rest period, if followed by untimely mild temperatures, may lead to much injury from later cold to tissues that have started to grow. This often happens to peaches in Missouri and southern Illinois, to red raspberries in western Washington, and to many other plants in many other locations. In such cases breeding and other efforts are directed toward intensifying and lengthening the rest period.

ADJUSTMENTS TO TEMPERATURE CONDITIONS

For the most part, the plant-grower takes temperature as he finds it and does little to change it. The most notable exception to this is in the greenhouse where it is possible to maintain almost any temperature that is desired, and the rapid, lush growth and excellent performance of plants grown under greenhouse conditions is to a considerable degree a measure of the importance of this feature of their environment. Temperature is likewise controlled in houses devoted to the culture of mushrooms, the forcing of rhubarb, and in a few other instances. Outdoor-grown plants, however, are subject to natural temperature conditions and changes.

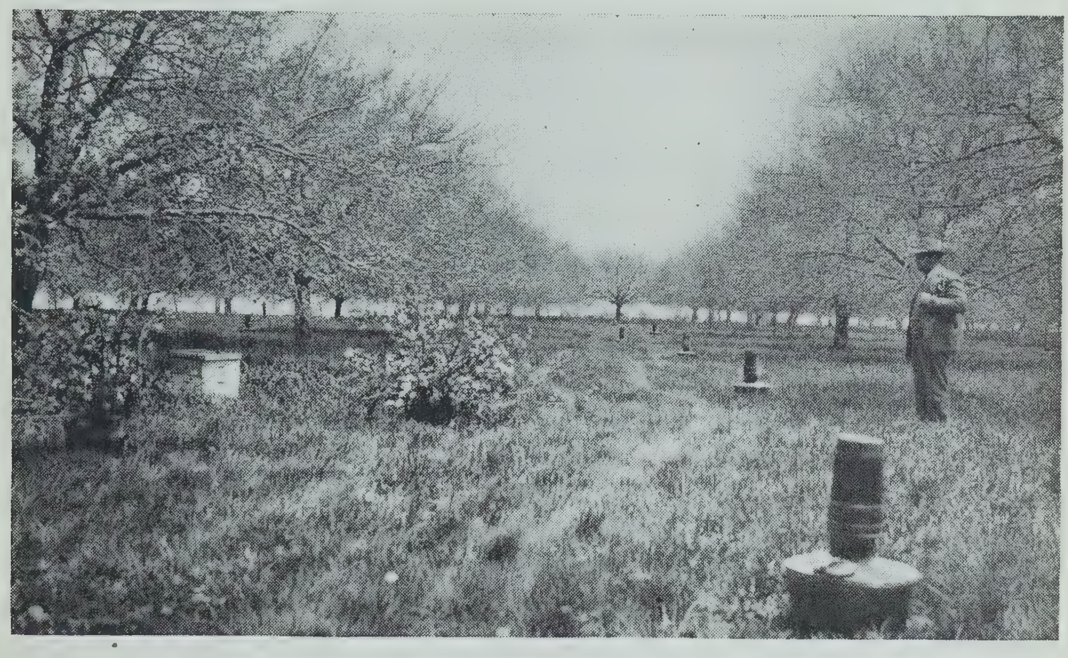

Fig. 56. An orchard scene just as the trees are ready to come into blossom. Orchard heaters have been provided to protect against frost, should that be necessary. Colonies of bees have been brought in to provide pollinating agents, and "bouquets" of flowering branches of other varieties have been placed in the orchard to insure at least a certain amount of cross-pollination.

Beyond such methods of rather complete temperature control as are possible in glass houses there are certain procedures, treatments, or practices which the grower may employ temporarily to modify temperature or to protect his plants from certain extremes. Thus, he can mulch them to protect their roots and crowns from very severe freezing. This is a regular practice with strawberries and many ornamentals in certain sections. Mulches likewise protect the soil from high temperature during the daylight hours of midsummer, something equally desirable with many cool-season plants. The grower can bend the plants to the ground, weight them down, and cover them for winter protection, a regular practice with grapes and bramble fruits in certain sections. He can train them against the south side of a wall so that they will receive reflected heat, as with fruit trees in some of the northern European countries. He can irrigate or flood with water, as in cranberry plantations, to protect against frost and freezing, or he can grow his plants under cloth or lath screens for the same purpose. He can even build numerous small fires or use orchard heaters to raise the temperature for short periods during the winter or spring, a rather common practice in citrus groves and occasionally in other plantations. An orchard-heater scene is shown in Figure 56.

All of these measures, however, except perhaps that of mulching, are rather costly, and some of them afford only very temporary protection. Far more important, effective, and economical are certain choices of location, kind, and variety that will result in a more complete adjustment of the plant to its environment and give some assurance that injury from unfavorable temperatures will be reduced to a minimum or perhaps entirely avoided.

THE SELECTION OF LOCATION AND SITE

Every farmer is aware of the profound difference between soils and of their influence on yield and quality of crop. He also knows that often there is a great diversity of soils within the boundaries of a single farm, sometimes in a single field, and insofar as possible he tries to capitalize on these differences by raising the crops on the several soil types best suited to them. Few farmers, however, realize that different areas, even different parts of the same field, present variations in temperature and other features of climate that, though perhaps less extreme, are more or less comparable to the differences in soil. From the standpoint of grains, grasses, and other forage crops these differences may not be of any great importance. From the standpoint of many horticultural crops they may be of extreme importance.

Some of the broader differences in temperature are indicated by the existence of the so-called "fruit belts," areas or strips of varying shapes and dimensions where the culture of certain fruit crops is possible or practicable. These fruit belts border, surround, or are surrounded by, other areas in which, because of temperature extremes of one kind or another, culture of the same crops is impossible or impracticable. The fruit belts along the eastern shore of Lake Michigan and the southern shores of Lakes Erie and

Ontario are cases in point. In these instances the prevailing winds sweeping across the open water bring cooling breezes in the summer, warmer air in the winter, delay vegetation in the spring, prolong the growing season in the fall, and thus protect vegetation for some distance inland from spring and fall frosts, summer heat, and winter cold. Nine or ten fruit crops may be harvested in a decade within these fruit belts, but perhaps only four or five crops can be produced a short distance beyond their borders, because of the difference in the number of killing frosts during the blossoming season. Location of an orchard enterprise within instead of without such an area is one of the fruit-grower's most practicable methods of dealing with the temperature problem. The best bulbs of many flowers (such as tulips, hyacinths, narcissi, and freesias) are produced where the growing season is fairly long, atmospheric humidity high, and spring and summer temperatures comparatively low. Thus, the so-called "Dutch" bulb industry has attained its greatest development in Holland and Belgium, and the Puget Sound and Long Island districts of this country. Casaba, honeydew, and Persian melons are raised successfully only in sections where there is a long, hot growing season.

Likewise of importance in the successful culture of many horticultural crops is the advantage that may be taken of rather small differences in temperature that are found between places only short distances apart, perhaps places on the same farm. These are occasioned principally by differences in exposure to wind or slope and by minor differences in elevation. Southern exposures, especially if protected from the wind, average several degrees warmer in summer than corresponding northern slopes; strawberries or tomatoes grown on them will ripen a few days earlier, and varieties of grapes that might be caught with frost on a less favorable location will mature on them. On the other hand, later maturity, often a valuable consideration, is obtained on a northern slope because of the lower temperature. Often a difference in elevation of even a few feet is responsible for frost at the lower level, while vegetation at the higher level escapes. This is due to air drainage, the gradual settling of the cooler, heavier air while the warmer, lighter air rises. These differences are important in the culture both of fruits and the tender or warm-season vegetables.

THE SELECTION OF TYPE AND VARIETY

In addition to utilizing the favorable condition offered by certain sections, locations, and sites as compared with others, the grower should take advantage of the differences between varieties in their temperature requirements. Indeed, for those who are already located and in possession of their land, that is about all that can be done. Often it is all that is necessary, for in many groups and even species of fruit, vegetable, and ornamental plants the diversity is so great that a wide choice is possible. If winters are extremely cold, as in Minnesota and the Dakotas, it may be impossible to raise Baldwin and Winesap apples, but that doesn't mean that the raising of apples must be foregone in that area. Wealthy, Northwestern Greening, Haralson, and many other hardy varieties may be planted. If summers are short and cool, it may be impossible to raise Catawba, Sheridan, and Isabella grapes, perhaps even the Concord, but it may be possible to raise the Fredonia and Ontario. If the summer temperature of Tennessee is too high to raise the Cuthbert raspberry, it is still possible to have raspberries by raising the Van Fleet. The Tom Watson watermelon that grows so well in Georgia and Alabama may not attain its normal size and quality in Ohio, but the Kleckley does and Northern Sweet matures high-quality fruits much farther north. As grown in New England, the McIntosh is an apple of highest quality; as grown in Missouri, it is barely mediocre; the reverse is true of the Winesap variety. McIntosh is a variety that attains perfection only where the growing season is cool; Winesap attains perfection only where the growing season is warm. Obviously, Winesap should not be grown in New England, nor McIntosh in Missouri. There are certain sections with intermediate temperature conditions where neither of these varieties reach perfection, and neither should be planted, though certain other varieties will grow very well. The native range of a species and likewise the cultural range of a variety are determined by other features of the environment as well as by temperature. A varietal list should be selected with all features of environment, together with market demand and other factors, in view; nevertheless, response or reaction to temperature is the most important single factor in determining where a variety can and should be grown. Similarly, varietal selection is the most important single tool in the hands of the grower of horticultural plants in dealing with the many peculiarities and extremes of his temperature conditions.

PROBLEMS

1. It has been stated that freezing kills plant tissue by cellular, as distinguished from tissue, dehydration. Explain what is meant.

2. Explain the difference between a frost and a freeze. Which do we find often accompanied by wind?

3. Peaches cannot be successfully grown out-of-doors in the Dakotas or in England. Do the same or different features of the environment account for this? Explain.

4. Explain why a so-called *fruit belt* has developed along the east side of Lake Michigan in the state of Michigan but not along its west side in Wisconsin.

5. Cabbage and carrots are classified as cool-season crops, zinnias and cantaloupes as warm-season crops. Peaches are classified as relatively tender and Duchess apples as relatively hardy fruit crops. Would you expect the areas where the tender peaches and warm-season vegetable and flower crops are grown successfully and the areas in which the cool-season vegetable and hardy fruits thrive to coincide closely, or not? Explain.

6. Grapes and watermelons are raised only in very limited quantities in New England. Are the specific reasons for this lack of successful culture the same with these two crops, or are they different? Explain.

7. Why is it that in many sections tomatoes are commonly started in greenhouses or hotbeds and then later transplanted to the field, while cucumbers are seeded directly in the field?

8. Is it adaptation to high or low growing-season temperature or is it length of growing season that determines whether eggplants are started in hotbeds or greenhouses and later transplanted to the field or are started directly in the field? Explain. Apply the same question for celery and head lettuce.

9. It is possible to make plants more resistant to cold by a hardening-off process. Would you expect this cold-resistant condition to be permanent or temporary? Why?

10. In temperate regions plants become progressively more resistant to cold in the fall and early winter. Would you expect them to become progressively more suceptible to cold injury in the spring? Why?

11. For the most part, jellies are made out of fruits harvested from plants that regularly become acclimatized each fall to endure considerable cold. They are not regularly made from fruits of plants that cannot be hardened (unless the jellying property of the juice is reinforced by pectin from some other source). Can you suggest any basic reason for this?

12. Why should cool nights and frosts in early fall tend to promote high coloration of fruit?

CHAPTER VI

WATER AS A LIMITING FACTOR

THOUGH water is perhaps not so all-pervading an influence as temperature, it ranks second only to temperature as a factor influencing growth processes. Ample evidence of this is found in the distribution of plants according to amount and distribution of rainfall and in the many structural modifications and physiological adaptations of the plants themselves in response to differences in moisture supply. Indeed, the difference in general appearance between, say, the desert cacti and water lilies is far greater than that between temperate-zone and subtropic- or tropic-zone species, and the cacti will not survive in the water nor water lilies in the desert any more than tropical plants will survive when taken to the far North. Furthermore, there are many different ways in which plants have become adapted to desert conditions on the one hand and living in the water on the other. For instance, most of the cacti have dispensed with foliage, their leaves consisting of spines or inconspicuous bracts (Figure 57), while the functions of leaves are taken over by the green stems. These are fleshy and consist largely of parenchymatous tissue in which sufficient water can be stored to tide the plant over months or even years of drought and are covered by a thick, almost waterproof cuticle. The bulbous plants of the desert survive by having very short periods of vegetative growth during the short rainy seasons of such areas, the remainder of the year being spent in the form of drought-resistant underground bulbs, corms, or tubers. The woody mesquite (*Prosopis juliflora*), manzanita (*Arctostaphylos glauca*) and chaparral, including such species as *Quercus gambetii*, *Adenostoma fasciculatum*, *Ceanothus cuneatus*, and *Cercocarpus parvifolius*, continuously exposed to the desiccating desert influences, have their stem and leaf surfaces so covered by cuticle or their stomata so protected by hairs that they can conserve their limited water supply almost as effectively as the cacti or bulbs. A dense covering of hairs protects the leaves of many plants from desiccation as effectively as does the waxy cuticle of others. The desert plants in general and also certain others which grow in more humid regions, but are capable of enduring or escaping extreme drought, are known as *xerophytes;* water plants are called *hydrophytes;* plants obtaining their nutrient and moisture supply from the air and depending on soil or other plants or objects only for mechanical support are called *aerophytes* or *epiphytes*. Though few belonging to these groups are of value in general farming, many are cultivated by the horticulturist, more especially for ornamental purposes. Hydrophytes of many kinds are used in pools and water gardens, and both hydrophytes and xerophytes, depending on amount of shade and exposure to sun, are used in rock gardens. Water cress (*Radicula nasturtium-aquaticum*) and rice are examples of hydrophytes used as food crops. Many aerophytes, such as the orchids, are raised as greenhouse ornamentals.

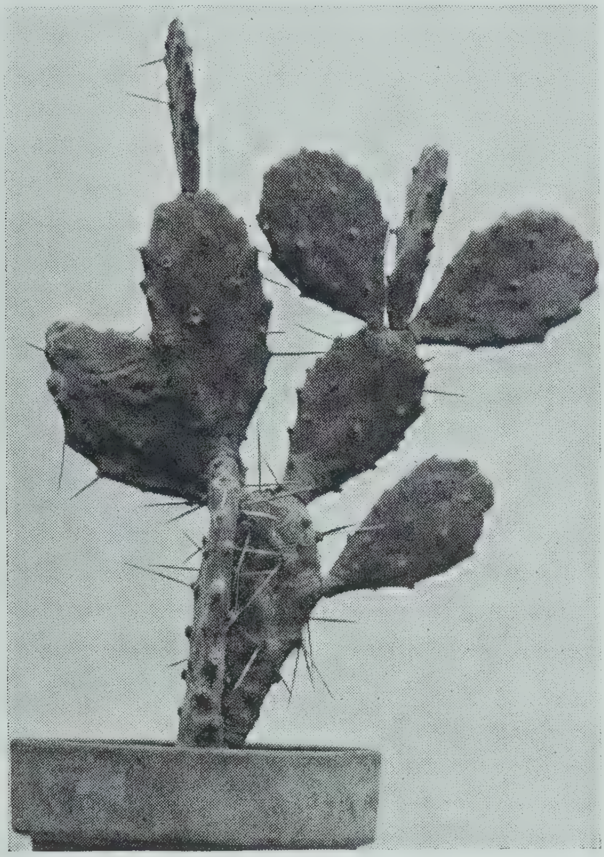

FIG. 57. A cactus plant (*Opuntia*) with stem and branches taking the form of thick "joints" that are shaped like leaves and that perform the functions of leaves. Their true leaves are reduced to inconspicuous bracts at regularly spaced nodes on the "joints."

Between the xerophytes on the one hand and hydrophytes on the other are many groups of both land and air plants classed together as *mesophytes*, that are adapted to more intermediate conditions. These range from orchids, lianas, and ferns, thriving along with many trees and shrubs in tropical or northern woodland climates, to the grasses of the prairies and pampas and include the great majority of crop plants — forest, forage, grain, fruit, vegetable, medicinal, and ornamental.

WATER AS A PLANT CONSTITUENT

Water is both an important plant constituent and a universal one. In nature there are no water-free plant tissues. The woody tissues of plants contain from 45 to 65 per cent water, depending on kind of plant and season of year. Usually the harder the wood the less moisture it contains. Ebony and oak contain less than willow; heartwood contains less than sapwood; and, as the dormant season comes on, both wood and other plant tissues give up some of their moisture. Thus, the midwinter moisture content of apple twigs may be as low as 45 per cent while that of the same twigs in summer may be 60 or even 65 per cent. The moisture content of the stem of a young, rapidly developing tomato plant may be as high as 90 per cent; two weeks later when properly hardened for transplanting it may be only 70 per cent. In general there is an inverse or negative correlation, within the same plant tissue and in the same kind of plant, between moisture content and hardiness, though there are many exceptions. Most fresh fruits contain from 60 to 85 per cent water, and some, such as the watermelon, from 90 to 95 per cent. Even "dried" fruits, such as raisins and prunes, contain 25 to 30 per cent moisture. Sometimes high moisture content is associated with a soft texture and lack of quality as in the case of berries maturing during or immediately following a prolonged rainy period; more frequently it is associated with rapid growth, tenderness, and crispness of texture. The crisp leaf stalks of the celery "heart" contain more water than the tough, stringy outer leaf stalks of the same plant; the tender pod of the string bean that "snaps" has a higher water content than the stringy string bean that is a few days older. The seeds of most plants, when in an air-dry condition, contain from 10 to 15 per cent moisture. Those of many plants, such as garden peas, when in prime condition for harvesting and using, may contain as much as 70 to 75 per cent moisture. Though retention of vitality for long periods depends on some of their other constituents as well, reduction of moisture content by thorough drying and then storage in a dry place is essential with the seeds of most plants.

Water not only is itself a constituent of all plant tissues, but it also enters more or less directly into the composition of most of the complex organic substances that make up the remainder of the tissues. Thus, a third of the weight of the starch, sugar, cellulose, and protein substances that are present has been derived from water that has been chemically combined with other substances to build up the finished products. This is *combined* water, as distinguished from that which is free that has been discussed in the preceding paragraph.

Thus, it is in more or less of a dual capacity, that is, both as an end product in the plant and as an ingredient entering into the make-up of other end products, that water serves as a plant nutrient.

THE ROLE OF WATER AS A MEANS OF OBTAINING OTHER NUTRIENTS

The amount of water retained by the plant, however, does not tell the most important part of the story, judged from the standpoint of the amount required for growth. Though analysis shows that only relatively small percentages of the substance of plant tissue are comprised of minerals that are obtained from the soil, these must be in solution in water in order to be absorbed. There is no definite concentration at which these minerals are absorbed by plants, as for instance an ounce of minerals with a pound of water, the proportions varying with conditions (a matter that is discussed in some detail in Chapter IX on "Water and Nutrient Intake, Translocation and Utilization"). Nevertheless, many times as much water is required to bring minerals into the plant as is retained by the plant as a part of its framework and substance.

The greatest water requirement, however, is in connection with the acquisition of the plant's supply of carbon — an element which makes up a considerable part of the bulk of the plant, greater by far than that of all the mineral substances put together, and which is not derived from the soil. The plant gets its carbon from the atmosphere in the form of carbon dioxide. Though air, and consequently carbon dioxide, surround the plant at all times, the

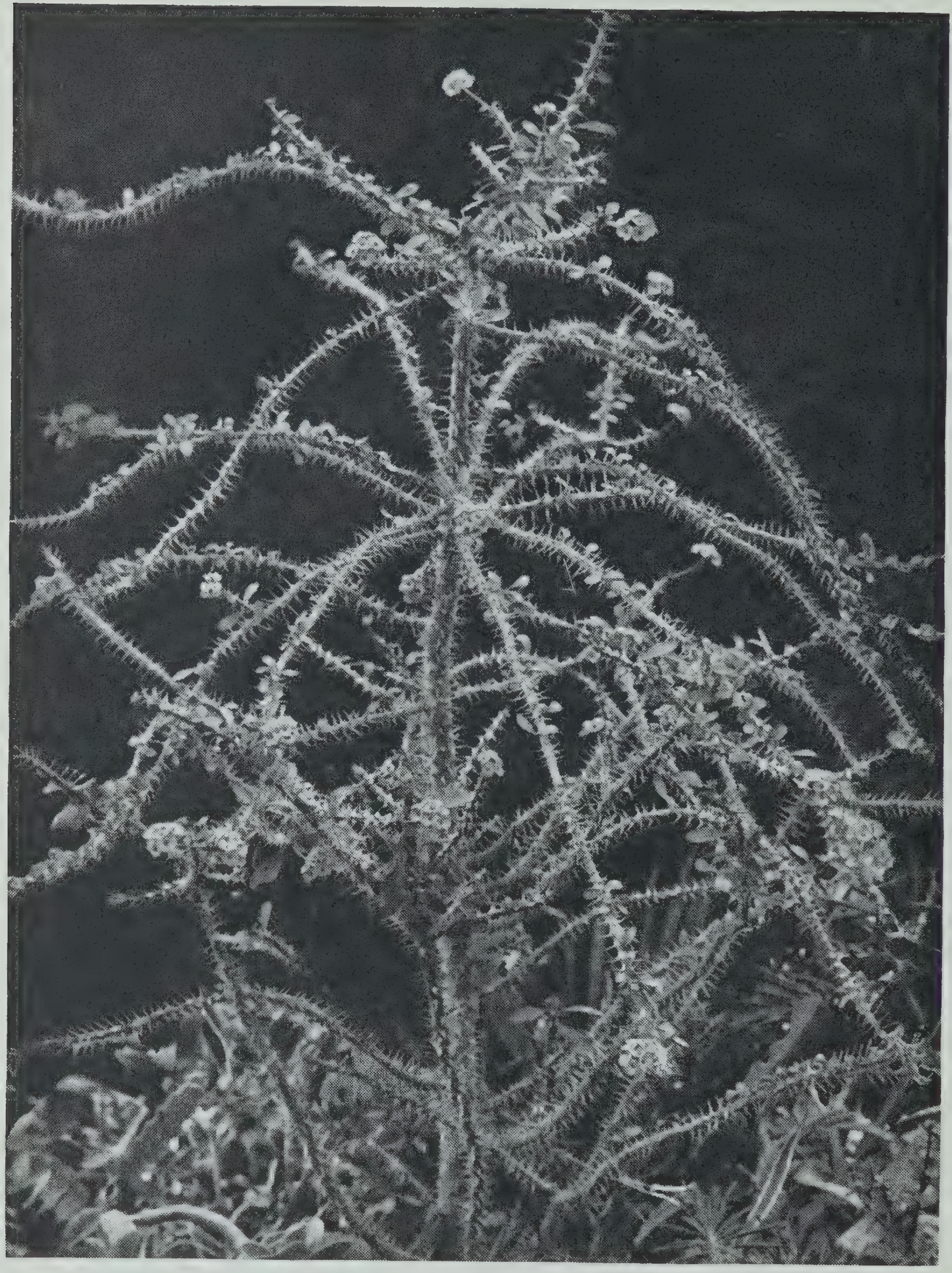

FIG. 58. A crown-of-thorns plant (*Euphorbia splendens*) in bloom. It is in full leaf as well as in full bloom, its very limited foliage production being a means of adaptation to conditions of drought.

plant can absorb it only after it has been dissolved in water. Some is dissolved in the water of the soil, but the plant does not obtain any appreciable amount from that source. Instead, it obtains its supply from what is dissolved in the thin films of water surrounding and adhering to the cells in the loose, spongy interior of the leaves — the so-called *spongy parenchyma.* The carbon dioxide reaches these water films largely through the stomata, is absorbed by them, and then passes through the cell walls into the interior of the cells where it is appropriated and used. The air which enters the leaf along with the carbon dioxide, however, is very seldom saturated with moisture; often it is very dry. Consequently, it has a drying effect on the water films; they become thinner, and the decarbonized air that escapes through the stomata from the leaves as other fresh air enters them is moisture-laden. The films of moisture must be constantly replaced by water from the parenchyma cells. They, in turn, must be replenished from the minute streams of the conducting vascular system which obtains its supply by absorption from the soil by the roots. What the whole process of water loss from the leaves amounts to from the standpoint of the plant's economy is an exchange, a trade, of water for carbon dioxide. The process of water loss from the plant is called *transpiration*, something that is more or less akin to the purely physical process of evaporation, but that is to be distinguished from evaporation because of a considerable degree of control which the plant itself exercises. In view of the low concentration of carbon dioxide in the atmosphere (about three fourths of 1 per cent) a large volume of air (at ordinary room temperature 13.6 cubic feet of air weighs one pound) enters and escapes from the leaf in order for it to obtain even a small amount of carbon. For instance, a bushel of potatoes weighing fifty-six pounds and which contains approximately five pounds of carbon, requires the carbon dioxide contained in some 20,000 cubic feet of air for the development of its tissues. Thus, in effect, the plant exchanges water for carbon dioxide, and water loss or transpiration is the price that it pays for its carbon.

The exchange rate varies greatly with different kinds of plants and with conditions. It is usually expressed in terms of the number of units of water absorbed for each unit of dry matter that is produced, and this is termed the *water requirement* of the plant. This ratio (water requirement) may be as low as 40 or 50 units of water for a corresponding unit of dry matter in some of the conifers, such as the pines and spruces, to as high as 2,000 to 3,000 parts of water for a unit of dry matter in certain leafy vegetables. The range for most crop plants under more or less average conditions is from 300 to 1,000.

If the air entering the stomata and circulating through the spongy parenchyma of the leaves is just moderately dry or if it is very dry, it takes up correspondingly moderate or large amounts of water in becoming moisture-laden, while it is giving up its carbon dioxide to the water films surrounding the cells. Thus, atmospheric humidity is a factor of considerable importance in influencing water requirement. Similarly, temperature and wind velocity, which likewise influence the evaporating power of the air, influence transpiration and water requirement, though much less profoundly than does the kind of plant. Plants in exposed, wind-swept locations have a relatively high water requirement as compared with those of the same kinds grown in protected situations. One of the important objectives in affording crop plants the protection of windbreaks is to enable them to use their moisture supply more economically, to reduce their exchange rate of water for carbon dioxide. High temperature increases water requirement not only through speeding up transpiration but through its accelerating influence on respiration, a plant process to be discussed later. Low soil fertility also has the effect of increasing water requirement, as compared with average or high fertility. It might naturally be assumed that this influence is brought about, in part at least, through the necessity of absorbing a greater amount of water in order to obtain the requisite amount of nutrients from a solution in which they are very dilute. Though the principle of selective absorption (to be discussed later) partially compensates for this, the fact remains that one of the most effective ways that the plant-grower has at his disposal to make a given supply of water produce the most plant tissue, the largest crop, is to see that his plants are provided with an adequate nutrient supply. One might almost say that when he fertilizes, he irrigates as well, though the larger crop naturally calls for a larger amount of water. In general, the minimum water requirement is associated with optimum growing conditions.

WATER REQUIREMENTS IN TERMS OF PRECIPITATION

It has just been stated that it takes 40 or 50 up to 2,000 or 3,000 parts of water, depending upon kind of plant and on conditions, for the plant to construct one part of dry matter. What do these figures mean in terms of precipitation? This depends in large measure on the amount of dry matter produced to the acre. If it be assumed that a crop of 300 bushels of apples or 600 bushels of tomatoes is produced to the acre, either crop would mean the harvesting of approximately 3,000 pounds of dry matter in the form of fruit, while another 3,000 pounds of dry matter would have gone into roots, stems, and leaves. If it be assumed, again, that in the formation of each pound of this dry matter 500 pounds of water is utilized, the total acre requirement would amount to 3,000,000 pounds — the equivalent of a six- to seven-inch rainfall. For double these yields a correspondingly greater amount of water would be required.

These figures, though, are only for the water that the plant actually absorbs from the soil, all but a very small proportion of which it transpires. It is generally figured that under average conditions and over a wide range of slopes, soils, and rainfall conditions a third of the rainfall either runs off the surface and into the streams without ever entering the soil, or percolates down so deeply into the soil that it is not reached by the plant's roots, and that another third is lost by surface evaporation, leaving only a third available for actual use of the plants. If most of the precipitation comes in the form of many light showers, evaporation losses are relatively greater and runoff and seepage losses less; if it comes in the form of a few torrential downpours, evaporation losses are less, and runoff and seepage losses are greater in proportion to the total rainfall. Evaporation losses from the forest floor will be light; they will be correspondingly heavy from land not covered with vegetation. Runoff losses will be relatively heavier from steep slopes and compacted soil; seepage losses will be relatively heavier from level land and porous soil. If, however, these rough estimates are approximately correct, a total precipitation of at least twenty inches per year is necessary for the production of average or normal crops. Many areas receive less than this, and their production of dry matter is correspondingly reduced. Thus, in many arid or semiarid sections of the west summer fallowing is practiced in growing wheat. This means that the land lies idle or "fallow" one year out of two so that two years' rainfall is utilized to grow a single crop.

CULTIVATION AND MULCHING

Incidentally, the statements that have just been made provide the basic reasons for cultivation, mulching, and a number of other horticultural practices. Indeed, the principal reason for hoeing and cultivating is to conserve water for plant use. Stirring the soil breaks any crust that may have formed and roughens the surface so that a maximum percentage of the rainfall will enter it, thus reducing runoff losses. On slopes, cultivation across them rather than with them, results in a greater percentage of the water being absorbed. It also destroys weeds and prevents them from using water that otherwise would be available to the crop plants. It has long been thought that cultivation likewise reduces surface evaporation, but the evidence indicates that little saving is effected in this way. In conserving moisture deep cultivation is more effective than shallow cultivation only when it is necessary to root out or cover the weeds and to roughen the soil so that there is less runoff. Furthermore, deep cultivation is likely to cut and destroy a part of the most active surface-feeding roots and thus directly check water and nutrient absorption and growth. This is especially to be avoided just before, during, and immediately following the blossoming period of plants grown for their fruits or seeds, when even temporary interference with water absorption is very likely to result in a poor "set" of flowers and fruit. Similarly, there is nothing gained by cultivating more frequently than is necessary to destroy weeds and to keep the surface porous and uneven enough to catch and absorb the rain.

The practice of mulching is employed for a number of purposes. In northern sections mulches are often used to blanket the soil and keep it from deep and severe freezing, thus protecting the roots, crowns, and other underground parts from winter injury caused by the low soil temperatures of midwinter. In other instances it protects against the heaving incident to alternate freezing and thawing by preventing early freezing of the soil and then by keeping it frozen once it does freeze. In northern sections a good covering of snow serves most effectively as a mulch. Another use of mulch under the extreme opposite conditions is to keep soil temperatures from rising so high in midsummer; this is important with many crops in many sections. Growing cover crops are often used for summer mulching, as in citrus groves in some of the interior valleys of California. More frequently, however, mulches are employed to supplement or take the place of cultivation as a moisture-conserving measure. As with cultivation itself, they are effective to the extent that they reduce surface runoff and enable the maximum percentage of the precipitation to enter the soil and then cut down the water lost through weeds by preventing their growth.

Straw, coarse hay, grass, corn stalks or other crop residues, sawdust, pine needles, peat, coarse sand and gravel, even specially prepared paper, are among the many materials that have been used for this purpose. Each possesses certain advantages and disadvantages. Gravel is probably the most effective, both from the standpoint of catching all the rainfall and reducing evaporation, and has proved very practicable under certain conditions, but presents serious mechanical difficulties under others. Peat is likewise very effective in absorbing rainfall, but it retains what it absorbs so well and then in turn loses it to the air that very little of a light precipitation penetrates even a moderately thick layer to become available to the plant's roots. On the other hand, under conditions of heavy rainfall or abundant irrigation it is an almost ideal mulching material for almost none of what seeps through it is lost by evaporation. It is used extensively on lawns, putting greens, and about trees, shrubs, and other ornamentals. Sawdust is effective in much the same way as peat, but possesses the disadvantage of yielding certain toxic substances that prove harmful to many plants; consequently, it is seldom used. Straw, corn stalks, and other crop residues are the materials most commonly employed, in view of the fact that they are effective, inexpensive, and rather commonly available.

IRRIGATION, CROP ADAPTATION, AND PLANT SPACING

Obviously, irrigation is a measure to supplement natural rainfall. Though there are few sections where precipitation is so low that no vegetation is supported, there are many in which rainfall is so limited that crop production is absolutely dependent on a supplemental supply. There are many other areas where perhaps a little irrigation at a critical period means the difference between a poor and a good crop. Six to eight inches of rainfall *actually available to the plant* for its growth have been mentioned as about the minimum for producing a 300-bushel apple, a 600-bushel tomato, or a comparable crop of some other kind. Under average conditions this means eighteen or twenty inches of total precipitation, if well distributed, in view of the toll taken by runoff, seepage, and evaporation. Such amounts, however, are inadequate for many crops and under many conditions. If the section is characterized by high temperature, low atmospheric humidity, a long growing season, and considerable wind, thirty or forty inches of water may be necessary for good crop yields, and if the normal precipitation is only twenty inches, ten or twenty inches of irrigation water must be applied. If, in addition, the soil is very open and porous, still heavier irrigation may be necessary.

On the other hand, if somewhat less irrigation water than is desirable is available or if it is lacking altogether, the farmer can perhaps raise a crop that has a relatively low water requirement and get along very well. Thus, cherries and apricots, which mature before midsummer and whose trees can get along on a very limited water supply after the harvesting season, can be grown without irrigation in many areas where pears, apples, or peaches must be irrigated if they are to succeed. In comparison with the size of their tops, grape roots are more extensive than those of apricots or prunes and can be grown with a more limited water supply. Kentucky bluegrass (*Poa pratensis*) is deeper rooted than bent grass (*Agrostis capillaris*) and therefore much better suited for lawns where rainfall is not frequent and abundant or cannot be supplemented by frequent watering. The fescue grasses (*Festuca ovina* and *F. rubra*), in turn, are more resistant to drought than is bluegrass and are therefore preferable to it in a droughty situation.

Another method of adjustment to a limited water supply, where water for irrigation is not available, is through wider plant spacing. The principal factor, of course, in determining how far apart to seed or set plants is the size that they normally attain under the conditions in question. Thus, while tomato plants are set some 3 or 4 feet apart each way, oranges and sour cherries are set 18 to 20 feet apart; apples, 35 to 40 feet apart; and pecans and English walnuts 40 to 60 feet apart. Spanish onions are spaced to stand 4 to 6 inches apart in the row under conditions where one inch is adequate for radishes. Similarly, the Wagener apple, which produces a semidwarf tree, may be planted at the rate of 40 or 50 to the acre whereas Baldwin should be planted only 25 or 30. A 4 by 6 foot spacing of the Ponderosa tomato is called for where 2 by 4 feet spacing is ample for the Victor or Dwarf Champion (see Figure 59). Fertility of soil also influences spacing distance, wider spacing being desirable in the less fertile soils, unless fertilizers are employed. Second in importance only to natural habit of growth, however, is moisture supply. Roots of most crop plants will range wide and deep for moisture, and consequently under conditions of limited water supply they can be widely spaced with the assurance that with such spacing they will obtain what is available and use it to better advantage than if planted closely. Thus, there are sections in northern Africa (with an *average* rainfall of 10 inches) where olives are planted 60 by 60 feet, while the ordinary planting distance is 20 by 20 feet where rainfall is adequate or irrigation water available. Sweet cherries that are planted 30 by 30 feet in the light sandy loam soils of The Dalles, Oregon, where the rainfall is 16 to 18 inches per year, are set 25 by 25 in the Willamette Valley, a hundred miles distant, where there is twice as much rainfall, in spite of the fact that the trees grow larger and actually require more water for their larger tops in the latter area. Tomato plants of varieties that are set at 4 by 4 to 4 by 6 foot distances in the western prairie states where summer precipitation is light are set at 2 by 4 to 3 by 5 foot distances in Michigan and New York.

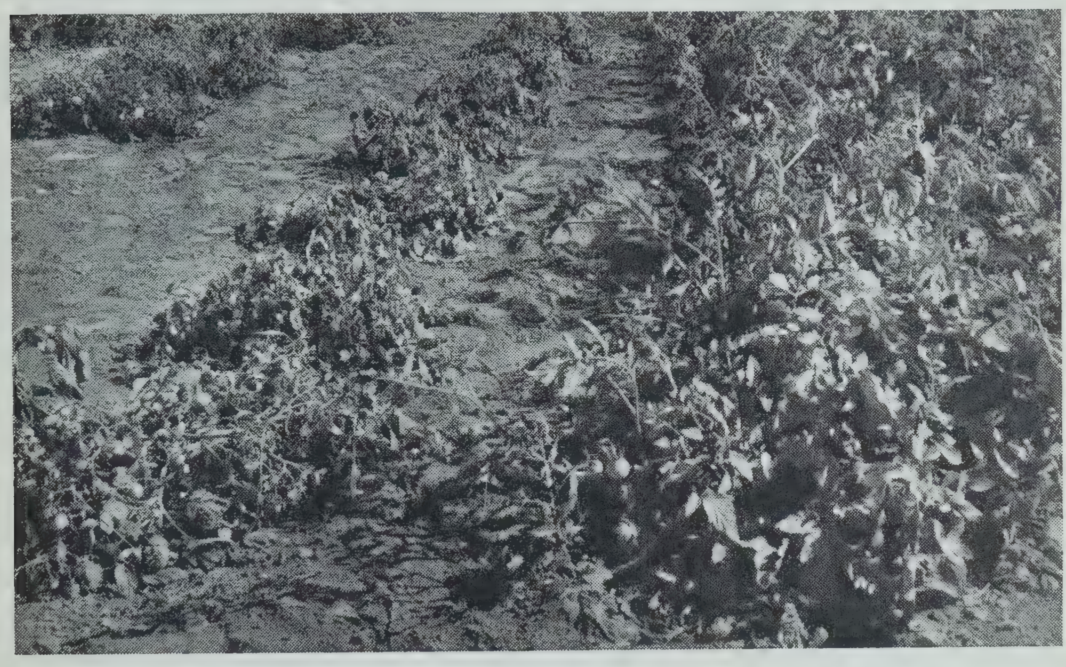

FIG. 59. On the left a dwarf-growing and on the right a standard tomato variety. The plants of the dwarf variety can be set much closer together than those of the standard.

Through (*a*) the selection of a soil whose physical properties are such as to supply relatively large amounts of water to the plant, (*b*) management practices that result in maximum penetration and retention of precipitation and irrigation water, (*c*) the choice of crop plants and varieties best adapted to his conditions, and (*d*) spacing the plants in accordance with those conditions, the grower has at his disposal four lines of approach to the solution of the problem of realizing the greatest returns from his land, his plants, and the labor that he gives to their cultivation.

Attention has been called to the fact that water requirement is greater in exposed, wind-swept locations than on protected sites. Increases in wind velocity have an even greater accelerating effect on surface evaporation than on water requirement, and hence windbreaks serve in a double capacity in the conservation of moisture.

WATER DEFICITS WITHIN THE PLANT

The roots of the living plant penetrate the soil in all directions, and the root hairs come into intimate contact with the soil particles so that through them a given volume of soil is well permeated and exploited. The films of water that surround the soil particles likewise surround the roots and root hairs, or perhaps it would be better to say that these films are continuous. As the water in these films surrounding the root hairs and rootlets is absorbed and taken into the tissues of the roots, the encasing films become thinner. As they become thinner their cohesive force tends to draw water away from the thicker films surrounding the adjacent soil particles and likewise those some little distance away. Thus, a flow of water is established in the direction of the roots, supplementing the growth of the roots into areas where there is more moisture, fairly rapid or active at first while the films are relatively thick, much slower a little later when they become thin. Finally a point is reached when the absorbing (osmotic) force of the roots can obtain no more water from the surrounding soil. This is known as the *wilting point* — a function of the soil rather than of the plant.

The water that is absorbed by the roots, together with the nutrients that it holds in solution, travels upwards in the plant, principally through the tubular (vascular) tissues of its bundles. Later it moves in its sapwood which has in the main developed from the bundles. Some of the water and some of the nutrients are withdrawn from this upward-moving stream to be utilized in tissue-building. Most of the water goes to the leaves where a little is used directly in the synthesis of various organic (food) substances such as sugar and starch, and the rest (by far the most) is transpired incident to the process of obtaining carbon dioxide from the air. The absorption of water by the roots on the one hand, its transpiration by the leaves on the other, are vital functions — that is, functions or processes of a living organism. The plant plays an *active* part in them; it doesn't just act passively as a kind of wick, drawing water out of the soil and evaporating it into the air mechanically. This is evidenced by the fact that a plant, such as asparagus, when killed by frost in the fall, at once almost stops as a water-absorbing and transpiring organism, even though the roots remain just as they were the day or week before, and the above-ground parts are changed little in size, shape, surface area, or general appearance.

Intake of water by the roots depends upon two main factors or groups of factors: (*a*) the available water supply in the soil and its air content, (*b*) the rate at which the leaves transpire. On the other hand, the rate of transpiration from the leaves depends on: (*a*) the evaporating power of the air, (*b*) light, and (*c*) the ability of the roots to absorb and the vascular tissues of the plant to transport water from the soil to replace that which is being transpired. Thus, slow absorption may check transpiration, or slow transpiration may check absorption, depending on which is the limiting factor at any particular time. Absorption is likely to be a limiting factor to transpiration during the day and transpiration a limiting factor to absorption at night. When absorption is lagging behind transpiration, the plant or some of its parts experience more or less of a strain or stress that is termed a *water deficit*.

Part of the water that is transpired by leaves escapes through the cuticle. This is known as *cuticular transpiration* and goes on night and day, little influenced by rate of water absorption by the roots but subject to the influence of temperature, wind velocity, and atmospheric humidity. Relatively more important, quantitatively, than the water lost through the cuticle is that which escapes through the stomata. It may amount to five or ten or even fifty times that lost through the cuticle. Characteristically, the stomata automatically close at night and open again in the morning under the influence of light. They also close during the day whenever the plant experiences more or less of a water deficit — that is, when transpiration exceeds absorption. In this way the plant possesses the ability to adjust itself to a varying moisture supply and also to varying atmospheric conditions. Whenever the stomata close, however, transpiration is virtually stopped, except for the small amount that takes place through the cuticle. That means that carbon-dioxide intake is correspondingly reduced, and consequently there can be but little synthesis of carbon-containing compounds. Growth is brought more or less to a standstill because access to one of the essential ingredients for growth is barred. Thus, limitation of the plant's water supply on the one hand or subjecting it to extreme desiccating influence on the other have the same effect — namely, to limit the manufacture of food. It is only during the daylight hours, and provided that temperature and moisture conditions are favorable, that the food-manufacturing equipment of the plant (its leaves) can function. One of the principal jobs of the cultivator is to see that those necessary conditions, especially an adequate moisture supply, are provided. That is why he prepares the ground so that it will hold as much water as possible and still be well aerated, why he cultivates to destroy the weeds, and why he spaces plants so that each one has all of the moisture that it can use advantageously.

When the moisture content of the soil in immediate contact with the roots and root hairs is reduced by absorption, the water that has been removed is replaced by a flow into that area from the surrounding soil; this tends to restore an equilibrium throughout the entire soil mass, though slowly in a compact soil. Similarly, within certain limits, when moisture is removed from the leaves by transpiration, their water content is restored by translocation from somewhere else in the plant until an equilibrium is reached. This, however, takes time, and not infrequently rather sharp localized deficits occur that may result in more or less permanent and serious disorders. Thus, when the flowers of many kinds of plants — for example, cotton, tomato, pecan — are subjected to severe drying even for a few hours at midday, they are very likely to drop off without setting and developing fruit. This is illustrated in Figure 54. Half-grown, or even full-grown fruits of the tomato that are still green are similarly desiccated by excessive transpiration from nearby leaves. They actually lose water, in part directly to the air and in part to and through nearby leaves which not only have the first call on the incoming water supply but are able actually to take water away from the fruits and cause them to shrink in size. The result, when the loss is extreme, is a disorder commonly known as *blossom-end rot*, shown in Figure 55. What happens is that the tissues around the "blossom end" of the fruit are so completely dried out that they die, turn brown and finally black, and become hard. Bitter pit or Baldwin fruit spot is a similar disorder of apples in which the dead tissue is in the form of flecks or pits scattered throughout the flesh. The winterkilling of the shoots and twigs of many shrubs and trees is due to their drying out in the winter when the water supply cannot be replenished because the ground around the roots is frozen.

The principle of rate of water absorption by the roots serving as a limiting factor to transpiration, operative during the day, and rate of transpiration serving as a check on water absorption, operative at night, has a number of important applications in connection with transplanting. Transplanting without a ball of earth, where all of the root hairs, most of the small feeding rootlets, and many of the larger conducting roots are broken off or dry out and die, leaves the plant practically with no water absorbing organs. It is for this reason that deciduous trees, shrubs, and vines are almost always transplanted while in a dormant condition, for then their bare tops lose very little moisture even if subjected to drying conditions for long periods. By the usual practice of pruning away a part of the tops their need for water to replace that lost from slow drying out through the bark is still further reduced. The drier the atmosphere or the more severe the root pruning incident to the digging process, the more severely should the top be pruned back. So completely does proper pruning back of the top reduce water loss from deciduous plants transplanted in a really dormant condition that tree losses are very small. On the other hand, if transplanting is delayed until the buds are breaking or have broken and evaporation through the bark is augmented by transpiration through expanded bud scales and exposed rudimentary leaf or flower tissues, plant losses from desiccation may be very heavy. Evergreen trees and shrubs, both narrow and broad-leaved, which cannot be pruned back without serious injury to their shape and value, should preferably be transplanted with a ball of earth around their roots — in nursery practice usually held in place by wrapping with burlap. This keeps intact at least a reasonable portion of their small rootlets and accompanying root hairs so that their leaves, which continue to transpire though perhaps more slowly than before, will be kept supplied with water.

If the soil is well supplied with moisture, it is usually preferable to transplant both deciduous and evergreen species at the beginning of or during the early part of their dormant season than near or at its end, for even though the tops remain dormant for days, weeks, or even months after setting, new roots will be formed and become well established before the beginning of the active growing season. The root system of such a plant is then well able to supply its top with water. In the case of plants set just at the beginning of the growing season, root and top growth must begin and proceed concurrently, and, if soil conditions are less favorable for root growth, if the soil is either dry or water logged, or if it is cold, top growth proceeds more slowly than it otherwise would. Deciduous trees, shrubs, and vines that are transplanted while in leaf must necessarily be moved with a ball of earth, just as are evergreens. Herbaceous annuals that are transplanted, from seed bed, greenhouse, or hot bed to the field, likewise are sometimes moved with soil around their roots for the same reasons, though with many kinds and under favorable conditions it is an unnecessary precaution. Watering at or shortly after transplanting is seldom necessary with deciduous plants that are set while in a dormant condition, but it is desirable with the evergreen species and annuals that are moved with a ball of earth.

SOIL MOISTURE

The soil in which plants grow is not a solid substance, like a bar of metal or piece of coal, but is made up of innumerable particles of many shapes and sizes between which are open spaces. These open spaces constitute varying percentages of the bulk or body of the soil, depending on conditions, but make up about half its bulk in most so-called *agricultural* soils. These spaces hold the soil water. When they are completely filled, as immediately after a heavy rain or irrigation, the soil is saturated. Normally, much of this water drains away, leaving each soil particle surrounded by a film of water. The water content of a soil in this condition is said to be at its *field capacity*. This water consists in part of so-called *capillary* water and in part of colloidally held water, the latter more or less comparable to the colloidal water of plant tissue. Under the influence of surface evaporation and perhaps absorption by the roots of plants, the moisture films become very thin, and the soil becomes "air dry." Air-dry soil still contains some moisture, the colloidal fraction, but not enough to support plant life. Indeed, plants will die from drought in soil whose moisture content may still be somewhat above the air-dry condition, because the soil particles hang on to very thin films of moisture with great tenacity, a force greater than that of the roots that may be trying to get it away from them. On the other hand, roots of most land plants die in a soil that remains saturated for any considerable period. This is not because they cannot obtain moisture and nutrients from such a soil but because it does not contain air, aeration being necessary for the continuance of respiratory and other life processes of the roots.

Temporary flooding of land or roots, even during the growing season, is seldom harmful, but if the roots remain covered for several days, root hairs and perhaps some of the younger roots will be killed. Longer periods of submergence are likely to result in the death of the entire root system. During the plants' dormant season, when they have comparatively few active root hairs, roots will survive considerably longer periods of submergence — sometimes several weeks or even months. Partial submergence occasioned by a rise of the water table, or ground water level, to within a few inches or foot of the surface and its remaining there for several days or longer, often causes serious crop injury if not complete loss, for the roots below the water level are killed, and only those in the shallow layer of aerated surface soil survive. These roots may be adequate for survival and a meager growth of the plant but inadequate for normal growth and production. This is well brought out in Figure 60. When loss of the deeper roots is thus caused by a high water table in winter or spring, and there follows a long dry period in the summer, the plants are especially subject to drought injury because of the shallow root system. Plants grown on land subject to a high water table and showing the characteristic symptoms are often spoken of as suffering from "wet feet." Injuries of this kind are common on poorly drained land, far more common than is generally believed, because the causal conditions are often not recognized. Perennial crops in particular should never be grown on land subject even at long intervals to a high water table, for a single rise in its level may destroy plants that have required years to grow to maturity, while only a single crop of annuals would be lost.

Between saturation and the wilting point, however, is a wide range in soil moisture content within which roots may function properly. As the saturation point is closely approached on the one hand or the air-dry condition on the other, growth processes are retarded because of inactivity on the part of the roots or their inability to absorb water as rapidly as it is required for maximum growth.

Soils of coarse texture — sand and light sandy loams — are not able to hold much water against the pull of gravity. The films of water on the surfaces of their large particles may be as thick as those on the surfaces of the smaller particles of fine-textured soils, but the surface area of the small particles per cubic foot of fine soil total is much greater. Hence, following a rain or irrigation less water drains away through fine-textured soils, and they have a greater amount of capillary or "available" water. The available water (that is, the water available to plants for absorption) in a coarse sandy soil may amount to only 3 or 4 per cent of its weight, whereas that of a clay or clay loam may amount to 15 to 30 per cent and that of a muck or peat soil to 30 to 60 per cent of its weight. It is for this reason that light soils are characteristically droughty and require more frequent and heavier rains or irrigation if they are to yield as heavily as those of finer texture. One of the main objectives in incorporating organic manures or other humus-forming materials in light soils is to increase their water-retaining capacity through the effect of the disintegration products on total particle area in the soil horizon where most of the roots are found.

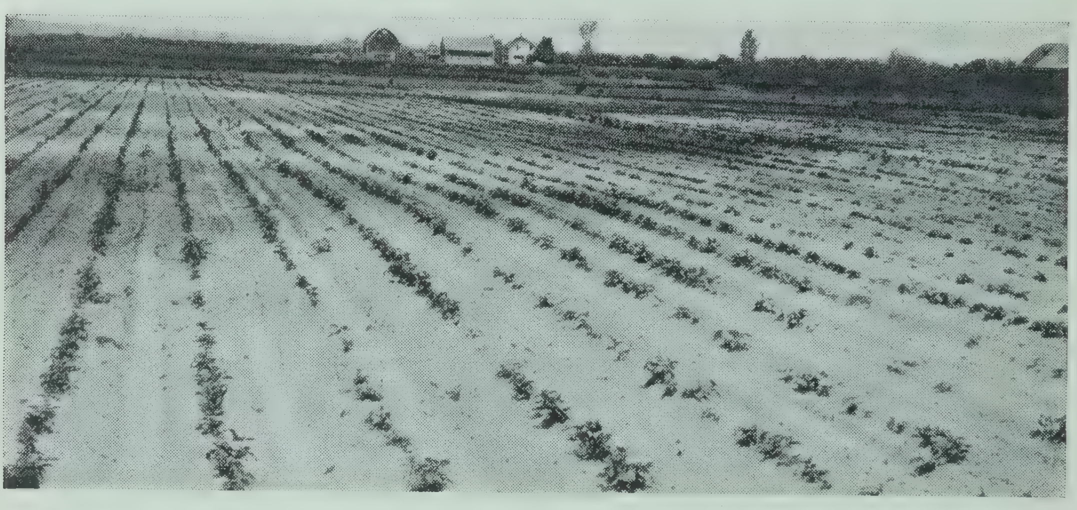

Fig. 60. Strawberries growing on a piece of level land. Variation in subsoil drainage, giving rise to localized "wet feet" conditions, has resulted in an uneven growth of the plants.

ATMOSPHERIC HUMIDITY

Atmospheric humidity is hardly less important than soil moisture as a limiting factor in the growth of plants. Theoretically, atmospheric humidity may range from 0 to 100 per cent; practically, it ranges from 10 to 15 per cent during a drought period in a very arid section to 100 per cent just before or during a rain or when there is a heavy fog or at some other time when the air is saturated with moisture. At ordinary living-room temperatures atmospheric humidities below 40 per cent are too dry and those above 70 too damp for most people's comfort. Usually low atmospheric humidity characterizes those sections where the soil moisture supply is likely to be limited, except as supplemented by irrigation. High atmospheric humidity is found in the areas of abundant rainfall; consequently it often is impossible to segregate or distinguish clearly between the influences of the two moisture factors. Thus, the greatly reduced leaf area (see Figures 57 and 58), the development of a heavy cuticle or the formation of a waxy surface layer, and the presence of other structures or devices that reduce transpiration characteristic of desert plants are in part responses to a limited supply of moisture in the soil and in part to low atmospheric humidity. There are, however, a number of plant responses, important in crop production, that are clearly due in the main to atmospheric humidity.

The north central plains states and the prairie provinces of western Canada contain vast areas that were treeless when first peopled by the white settlers and that for the most part remain treeless to this day, in spite of long continued tree planting. To some extent this doubtless has been due to the prevailing low winter temperatures, but to a far greater extent it has been due to desiccation of their woody tissues in midwinter because of the dryness of the atmosphere. High atmospheric humidities, on the other hand, probably more frequently set the limits for the practicable culture of many fruits, vegetables, and ornamentals, not directly through causing the death of the plants but indirectly through providing conditions favorable for the development of certain fungi that in turn limit the range of the crop plant in question. Thus, apple scab abounds in regions of high humidity and causes little trouble in arid sections. Plums, apricots, and sweet cherries are grown in relatively limited quantities in the southeastern

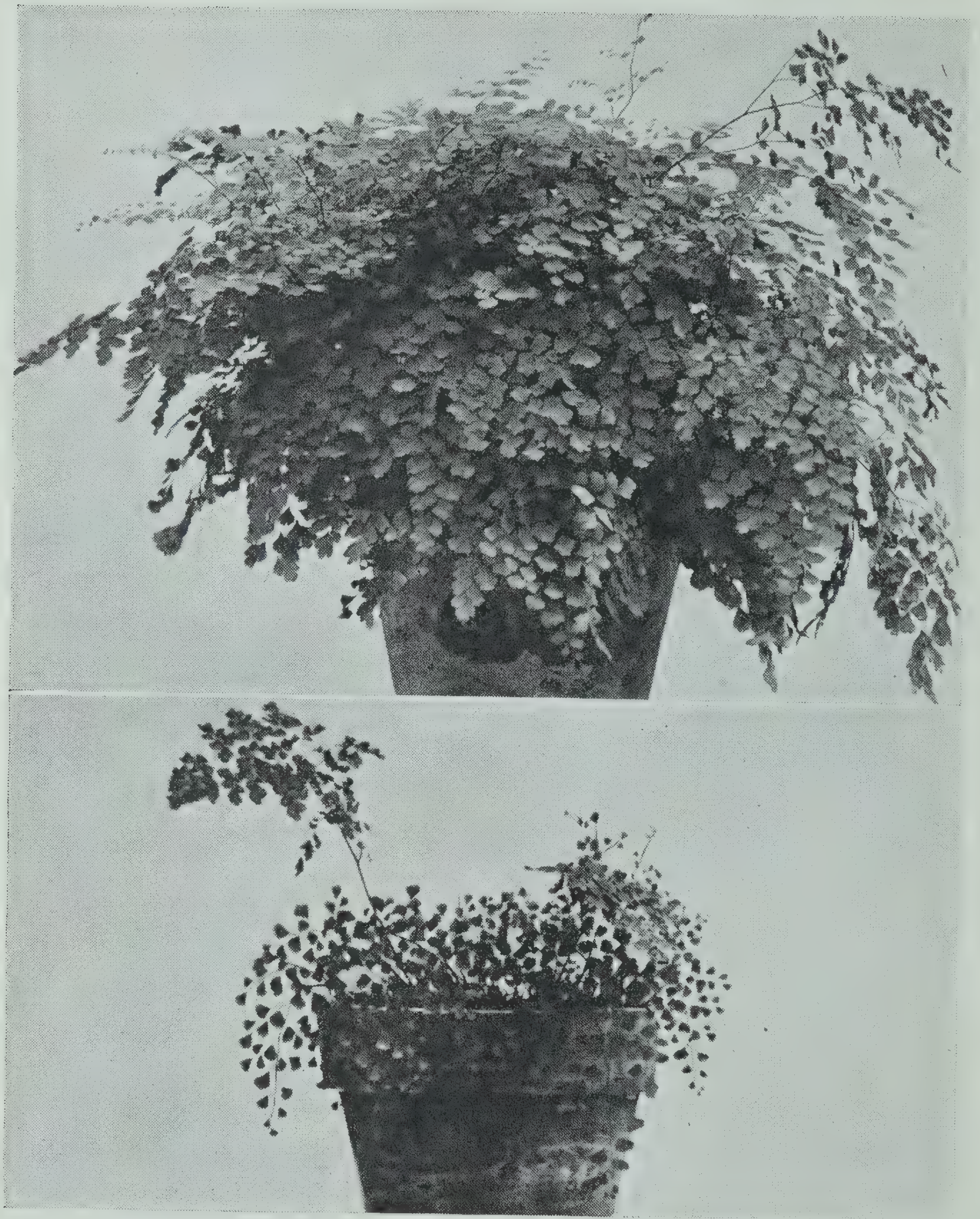

Fig. 61. Above is a photograph of a maidenhair fern (*Adiantum capillus-veneris*) as it came from the moist atmosphere of a greenhouse. Below is a photograph of the same plant as it appeared after exposure to the relatively dry atmosphere of a classroom for two months. Compare with Figure 62.

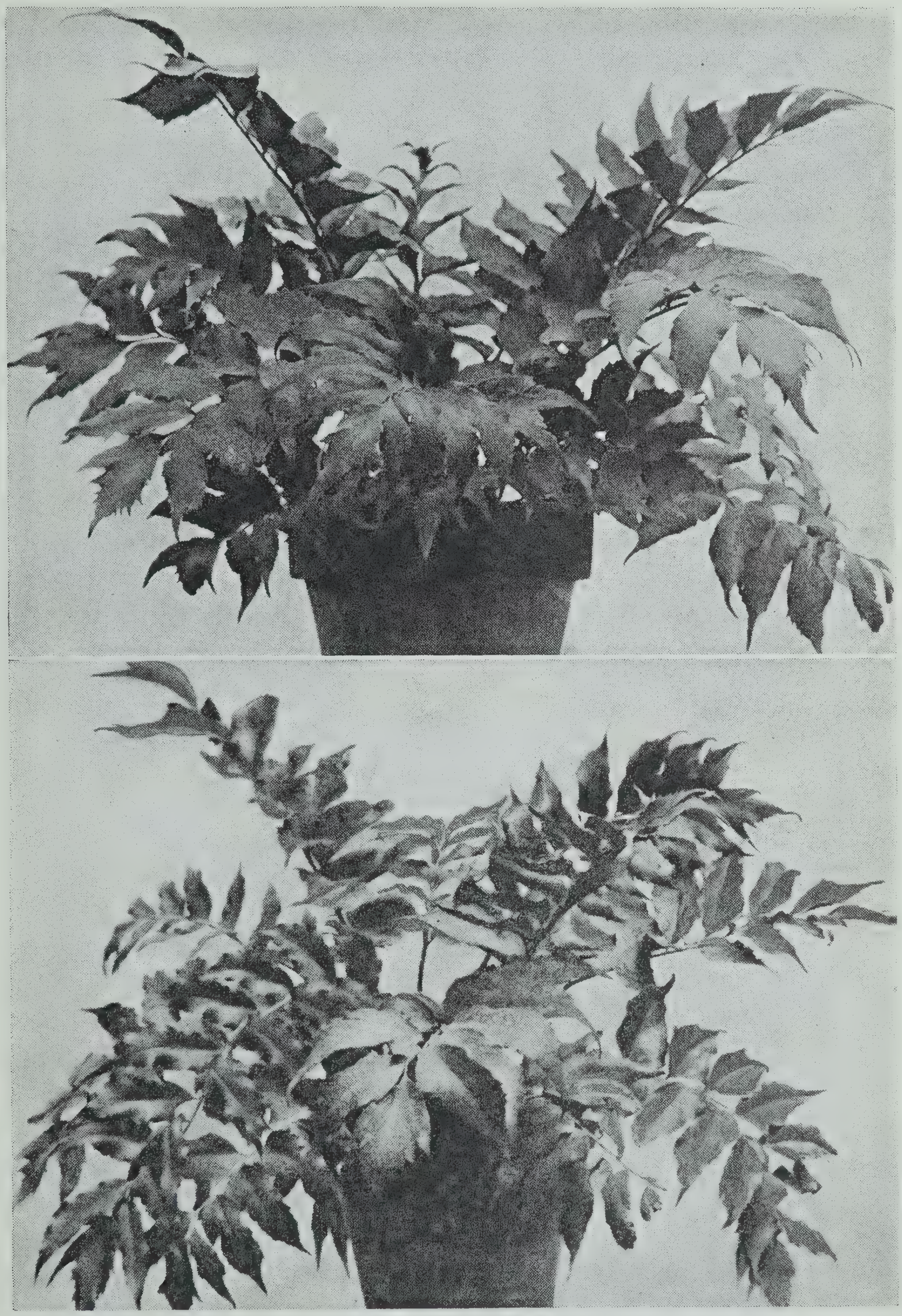

Fig. 62. Above is a photograph of the house holly fern (*Cyrtomium falcatum*) as it came from the greenhouse the same day as the maidenhair fern shown in Figure 61. Below is a photograph of the same plant as it appeared two months later after exposure to the dry atmosphere of a classroom. Note its ability to tolerate atmospheric drought, as compared with the maidenhair fern.

quarter of the United States principally because of the prevalence of brown rot in that area. The commercial bulb industry has developed in certain areas, such as Holland, the Puget Sound section of Washington, Long Island, and Michigan, in part because of the prevailing cool growing seasons but more particularly because of the humid atmosphere.

In sections with a dry atmosphere the skin of fruits like the apple and pear acquires a high glossy finish; in humid sections the same fruits have a dull finish or become more or less russeted as they approach maturity. High finish, however, is a matter of surface and is not correlated with interior flesh quality. Sweet cherries and figs are subject to cracking and subsequent fungus infection if atmospheric humidity is high and there is much rain, fog, or dew during the week or ten-day period just before harvest. Dates can be grown successfully only in regions of low atmospheric humidity.

Many of the species and varieties of plants commonly used as house plants are chosen for their ability to endure extremes of both soil and atmospheric moisture. The sword plant (*Sansevieria zeylanica*), the India rubber (*Ficus elastica*), the asparagus "ferns" (*Asparagus plumosus* and *A. sprengeri*), *Aspidistra*, the English Ivies (*Hedera helix*), screw pine (*Pandanus veitchii*), and pothos (*Scindapsus pictus*) are examples of foliage plants of this type. The Christmas cactus (*Zygocactus truncatus*), cyclamen (*Cyclamen persicum*), calla lily (*Zantedeschia aethiopica*), and African violet (*Saintpaulia ionantha*) are flowering plants that similarly are tolerant of moisture extremes, especially a dry atmosphere. On the other hand, such kinds as the maidenhair fern (*Adiantum capillus-veneris*), elephant's-ear (*Colocasia esculenta*), most of the crotons and orchids, the bird-of-paradise flower (*Strelitzia reginae*), and many others are sensitive to drought, particularly a dry atmosphere. Their culture should be attempted only where it is possible to provide for them the rather exacting moisture conditions which they require. Some idea of the differences between plants in their susceptibility to low atmospheric humidity is afforded by Figures 61 and 62.

SYMPTOMS OF MOISTURE SURPLUSES AND DEFICIENCIES

Plants react in different ways to too much or too little water, for their normal growth. In some instances the symptoms appear well in advance of the time or point where permanent injury has been effected or is imminent; in others much injury, perhaps irreparable, has been caused by the time clear-cut symptoms may be detected.

Probably the most common indication of a water deficit is wilting or "flagging" of the leaves. They simply become limp from loss of water and droop. This drought effect is more frequently noted in plants with thin than in those with thick, stiff, more or less leathery leaves, and in the newly formed leaves at the ends of growing shoots, though there are many exceptions. Temporary wilting during midday while the roots are unable to supply the leaves with the amounts of water being transpired is of very frequent occurrence. Wilting results in a closing of the stomata and thus in itself affords some protection against further water loss. With a lowering of temperature or a decrease in light intensity or wind velocity which will enable the water absorption to overtake transpiration, turgidity of cells and tissues is restored, and the leaves resume their usual positions. In those extreme cases where permanent wilting occurs, it is the oldest leaves that dry out the most and are killed first, with the youngest ones surviving the longest. For the older and lower leaves to wilt permanently and die as new ones are formed further up on their stems is an entirely normal process in many plants, for example, many varieties of *Phlox*, the snapdragon, golden glow (*Rudbeckia laciniata*), and the sunflower. It is usually not thought of as a drought effect, for it occurs more or less regardless of drought conditions. It is in reality due to the fact that the plant's root system grows to only about a certain size, a size that is able to supply water for only a certain amount of foliage.

Leaves of the corn plant, and many others, roll during periods of drought. Rolling, like wilting, affords some protection against further water loss. Those of many plants, as the potato, tomato (see Figure 63), and cherry, show a tendency to curl upon incipient drying. Many plants shed some of their leaves, always their older ones, as drought conditions develop and thus adapt themselves to a diminished water supply. This is comparable to the permanent wilting that characterizes many others. A good plantsman learns to recognize the very first symptoms of distress, so that, if practicable, the situation can be dealt with promptly, and further injury avoided. A rather characteristic symptom of drought in herbaceous plants, though perhaps not so readily evident as the above leaf symptoms, is the premature lignification that takes place in stem, root, and leaf tissues. This is evidenced by the premature development of stringiness in celery and rhubarb leaf stalks, strings in string beans and asparagus, pithiness in radishes and a number of other root crops, and a general change in many other tissues from a tender, crisp to a tough condition.

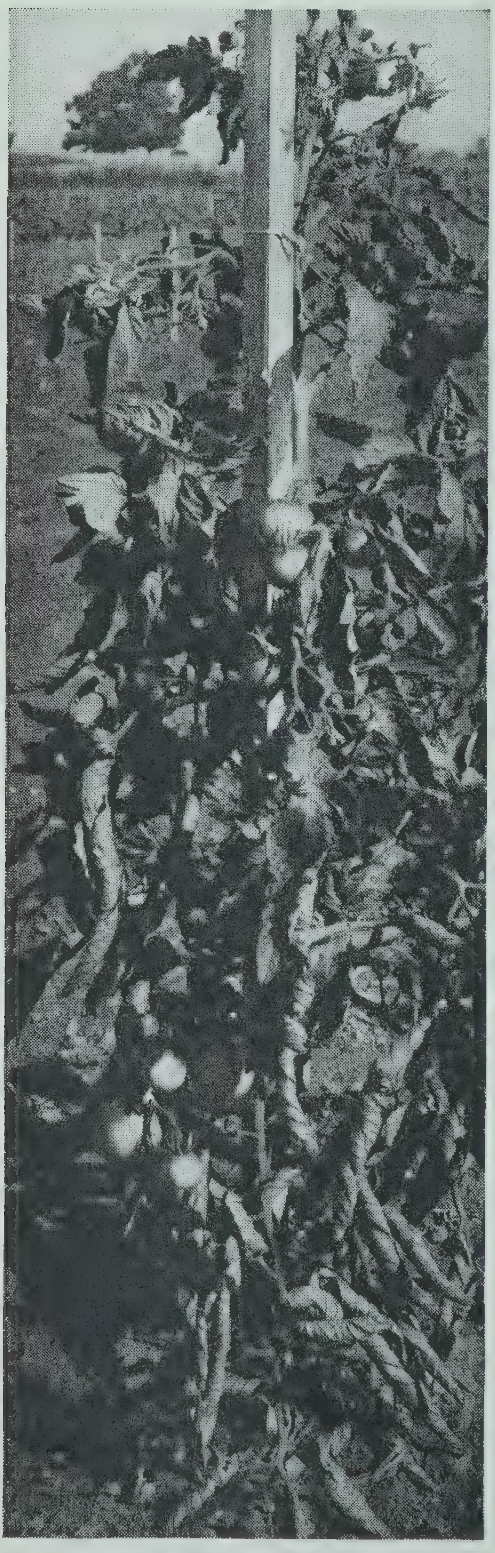

Fig. 63. A staked tomato plant whose lower leaves are much curled as a result of drought.

Odd as it may at first seem, the symptoms of a surplus or excess of water — those associated with a waterlogged condition of the soil or a high water table that destroys part of the root system — are often very much like those due to drought. This is understandable when it is realized that the excess soil water destroys a part of the root system and interferes with the proper functioning of the remainder through lack of aeration; thus, the root system as a whole can actually absorb less water than under normal soil conditions, and the top of the plant as a whole in reality suffers from drought. Injury from surplus moisture, however, in contrast to that caused by a deficiency in soil moisture, is likely to be accompanied by more or less yellowing of the foliage. In the case of trees and shrubs a high water table is likely to result in retarded growth and more or less dwarfing. Figure 64 shows the influence of both a too high and a too low water table on the growth of the high-bush blueberry. Herbaceous plants, in particular, that grow in a soil where there is an overabundance of water, though not enough to bring about the extreme effects that have just been noted, are likely to make a very rank, succulent growth and are therefore especially subject to breakage and uprooting by the wind and to infection by fungi of various kinds, especially those causing damping-off and other forms of stem rot. Still another evidence of too much soil moisture is the tendency of certain plants to produce aerial roots where under more normal conditions few or none are formed.

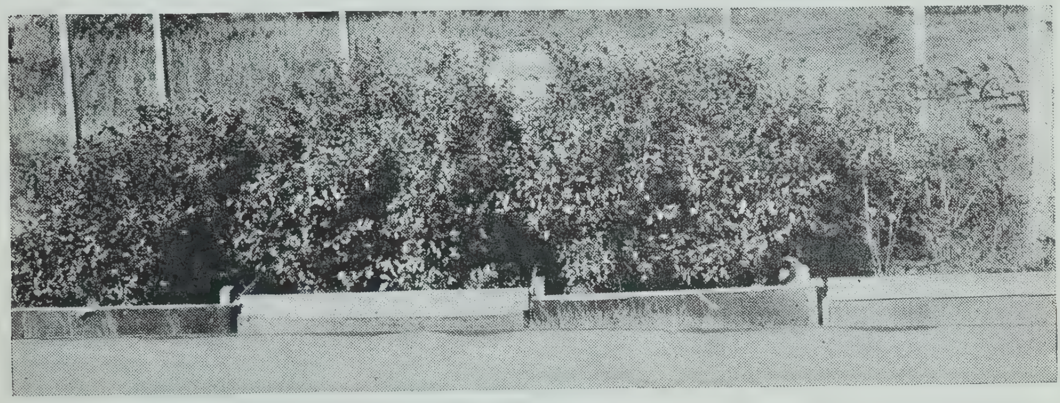

Fig. 64. The water tables under these four groups of high-bush blueberry plants had been maintained at 30, 24, 18, and 10 inches for four years at the time the photograph was taken. Note that the 24- and 18-inch levels have provided favorable conditions for growth, the 30-inch level less favorable conditions and that the plants have made poor growth above the 10-inch level.

PROBLEMS

1. For a given kind and variety of plant should nutrient or moisture supply govern distance of planting: (*a*) In a soil with abundant nutrients and a high water table? (*b*) In a deep fertile loam with a low water table? (*c*) In an infertile sandy loam with a limited nutrient supply and a high water table? (*d*) In a sandy loam with a limited nutrient supply and a low water table? Explain.

2. On which would you expect frequency and thoroughness of cultivation to have the greatest influence and on which the least influence: (*a*) size of crop, (*b*) quality of crop, (*c*) earliness of crop? Explain why.

3. Would you expect several midsummer cultivations to a depth of three or three and a half inches, each of which results in considerable injury to surface roots, to cause more serious damage to the crop in the case of tomatoes which are grown for their fruits or potatoes which are grown for their tubers? Explain why.

4. What arguments can you give in favor of and against hill, as compared with level, cultivation?

5. Would you expect the necessity of cultivation to be more frequent early in the season, or late? Why?

6. Would you expect it to be desirable or necessary to cultivate more or less frequently in a relatively dry season or climate than in a relatively wet one? Why?

7. Would you expect the deeper cultivation to be necessary in fields where the predominant weed population is of annuals or in fields where it is of perennials? Why?

8. Some advise deep plowing and deep fitting of land before planting vegetables, and then deep cultivation afterwards. Some advise the deep plowing and fitting beforehand, followed by shallow cultivation afterwards. Others recommend shallow plowing and fitting before planting, followed by deep cultivation after planting. Still others recommend shallow plowing and fitting before planting, followed by shallow cultivation afterwards. Which is the best procedure and why? Which is the poorest and why?

9. In northern sections cabbage plants for the early crop are transplanted to the field very early in the season, before frosts are over; tomato and melon plants for the early crop are transplanted to the field considerably later. With which is it necessary to transplant with the larger ball of earth and the least disturbance to the roots? Why?

10. Is a deep and thorough preparation of the seed bed so as to make it loose and mellow more important with cabbage or with carrots? Why?

11. Classify the following as xerophytes, mesophytes, epiphytes, or hydrophytes: (1) umbrella plant (*Cyperus alternifolius*), (2) pineapple (*Ananas sativus*), (3) orchid (*Cattleya trianaei*), (4) skeleton plant (*Euphorbia candelabra*), (5) hollyhock (*Althaea rosea*), (6) Spanish moss (*Tillandsia usneoides*), (7) sword plant (*Sansevieria zeylanica*).

12. In general would you expect a direct or an inverse correlation between water content and quality in fruits? In vegetables? In flowers? Give examples and explain why.

13. In general would you expect a high correlation — and would it be direct or inverse — between lasting quality of flowers and their free or their colloidal or their osmotically held water? Explain why, and give examples.

14. In general would you expect a greater correlation — and would it be direct or inverse — between the storage quality of fruits and vegetables and their free or their osmotically held or their colloidally held water? Explain why and give examples.

15. Which presents the more favorable conditions for the growth and health of plants and why — a very short period (for example, twenty-four hours) with the land covered to a depth of several inches with water but otherwise with a low water table or a longer period (for example, two weeks) with a water table only six inches from the surface but no flooding?

16. Would you expect a rather high water table for a considerable period during the winter or early spring to be more serious in a strawberry plantation or in an apple orchard? Why?

17. Would you expect a rather high water table for a considerable period during the winter or early spring to be more serious in a vineyard or in a melon plantation? Why?

18. Would you expect more or less blossom-end rot in tomatoes grown in an area protected from the sweep of the wind or in an area exposed to its full sweep, other conditions being the same? Why?

19. Why do vegetable and flowering plants often wilt severely for several days after pricking off or transplanting and then fail to wilt after a few days? Does the wilting hurt them?

20. Do you see any advantage in transplanting plants to the garden in late afternoon, as compared to early morning? Or in early morning, as compared with late afternoon?

21. Would these same advantages and disadvantages be found in the case of woody evergreens (for example, junipers and rhododendrons)? Explain.

22. Would they apply in the case of deciduous trees and shrubs transplanted during the dormant period? Why?

23. What is the relationship, if any, between the water content of a plant's tissues and its water requirement?

24. What factor or factors influence both evaporation rate and transpiration rate? What factor or factors influence one without influencing the other?

25. Explain the difference between a physical and a physiological process. Give an example that illustrates the difference.

CHAPTER VII

LIGHT AS A LIMITING FACTOR

IN THE preceding chapter the statement was made that comparatively dry air surrounds the leaves and that the atmosphere within them — in the network of open space among and around their spongy parenchyma cells — is moisture-laden. Diffusion which takes place largely through the stomata and accounts for the intake of carbon dioxide as well as the egress of the water vapor, depends largely on the size of the stomatal opening. This in turn varies with light conditions and moisture supply, but principally with light conditions when moisture is not a limiting factor, for the stomata close at night and remain closed until the next morning, when they open in response to the influence of light. Light then is the most important factor which determines whether or not a supply of carbon dioxide is actually available to the food manufacturing tissue of the plant, the green parenchyma within its leaves. Not only does light determine how much carbon dioxide enters the leaf, but it supplies the energy required for *photosynthesis*, the process in which carbon dioxide of the air is united chemically with water to form glucose sugar. Since glucose sugar is the starting point for the synthesis of all other carbohydrates and in turn for proteins, oils, waxes, and other organic compounds, which make up the bulk of the plant, the extent to which plants depend on sunlight becomes obvious.

LIGHT INTENSITY

Though in most plants the rate of photosynthesis is not reduced materially over that taking place in full sunlight until light intensity is cut down to less than a third or even a fourth of that amount, any further reduction is attended by a corresponding reduction in photosynthesis. On a dull cloudy day with light intensity at 10 per cent of full sunlight, photosynthesis will be reduced by two thirds. Similarly, the shade afforded by a tree of average density to vegetation growing beneath it may reduce light intensity to less than 10 per cent of that of full sunlight. The leaves on the lower branches of a dense shade or fruit tree may receive so little light because of shading from above that they can work at only a small percentage of full capacity. One of the main reasons for pruning, staking, and trellising the trees and vines of the orchard and vineyard and the plants of a number of garden crops is to spread out their leaves so that they will receive the maximum amount of light possible. The slow growth and limited flower production of most greenhouse plants during the cloudy days of midwinter in many northern sections are in part an effect of the shortness of the days, but to a still greater extent they are the result of low light intensity. Attempts to increase light intensity artificially through the use of electric or other lights have proven too expensive to be practical.

Though a certain moderate light intensity is necessary for maximum photosynthesis, exposure to sunlight of very high intensity harms some plants — in part, by directly checking photosynthesis, in part, by increasing transpiration, in part, by retarding growth (cell division and increase in bulk), or in other ways. Usually the higher temperatures and lower atmospheric humidities that are often associated with high light intensity operate along with that factor to influence in the same direction the various functions and growth processes of plants. It is often impossible to separate the combined effects and attribute to each its particular influence. The dwarfing of many plants, such as the so-called *alpines*, when grown at high elevations, however, is probably in large part due to light intensity, though short growing season is doubtless a contributing factor. Conversely, the spindly growth of many plants that are more or less crowded is largely an effect of shading. On the other hand, many species grow normally in the partial or even dense shade of forests or jungles and are known as shade-tolerant or shade-loving plants. Most of the ferns are distinctly shade-tolerant, and under cultivation they are usually grown most successfully in partial shade. Many crop plants, as, for instance, ginseng (*Panax quinquefolium*), thrive better in partial shade than in full sunlight and are regularly grown under lath screens. The leaves of the cigar-wrapper types of tobacco acquire a finer texture when grown in partial shade than in full exposure, and the better grades used for this purpose are produced under screen or cloth shelters, though part of the difference in quality in this instance is due to the higher humidity and lower temperature of the shaded area. Some of the varieties of English ivy (*Hedera helix*) and of pothos (*Scindapsus pictus*), mentioned in the preceding chapter as being especially tolerant of drought, are likewise able to thrive where they receive light of low intensity; hence, they do exceptionally well as house plants.

The greenhouse manager and nurseryman have a nice problem, or series of problems, in light exposure in the management of their cutting beds. Unless the cuttings are shaded at first, they will wilt and die; if shaded continuously, they are subject to decay before rooting because they do not contain a sufficient supply of stored foods to form roots. This limited food supply must be supplemented by what can be manufactured by their own leaves, and for this process light is needed. Hence, the proper procedure for them is a kind of middle course between an exposure in which they are lost from wilting and another in which they are lost through decay. Consequently, they are completely shaded for a few days; then they are gradually exposed to more and more light each day; by the time roots are starting to form, they may be enduring full exposure to normal sunlight. The length of time they are exposed to these different light conditions varies with the time of year and with the kind of plant. Frequent watering and syring-

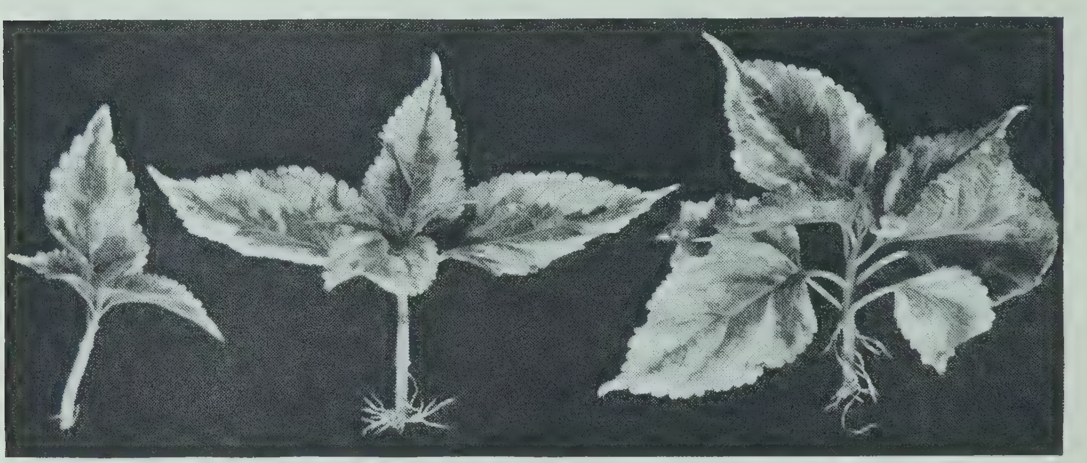

FIG. 65. Rooted soft-wood cuttings of *Coleus verschaffelti*. They were of the same size, taken at the same time, and handled in the same way. The one at the left had most of its leaves removed; the one in the center had some of its leaves removed; the one at the right had none removed. Root formation has been in proportion to the amount of foliage retained by the cuttings.

ing to keep the rooting medium at "field capacity" and to maintain a high atmospheric humidity are important aids, especially at first, in preventing wilting. Figure 65 affords some idea of the importance of the amount of light reaching their foliage on the rooting of *Coleus* cuttings.

One of the practical problems that faces every landscape gardener and a large proportion of homeowners is the selection of ornamentals for locations characterized by different light intensities. Many kinds that thrive in the full sunlight of an east, south, or west exposure do very poorly or even die when planted on the north side of buildings or where they are otherwise shaded. Even the establishing of a lawn may present more or less of a problem in the choice of different species or varieties of grass that will endure dense shade or intense sunlight, and many seedsmen and nurserymen list special kinds or varieties to meet these special conditions. More frequently they attempt to aid the amateur gardener in solving this problem by including in their lawn-grass "mixtures" seeds of several species or varieties, some of which are tolerant of shade and some of which do best in bright sunshine, so that, regardless of light conditions, a good turf will be formed. The kinds that will come to dominate the stand in the shade, however, will be different from those that will eventually dominate in the sun.

ETIOLATION AND BLANCHING

Leaves and other organs, as stems, that develop in the absence of light are without green coloring matter and are said to be *etiolated.* Such development takes place regularly when conditions are provided that are favorable for normal growth, except for the presence of light. The interior leaves of cabbage and of head lettuce are naturally etiolated. Production of etiolated shoots, leaves, or leaf stalks is the principal objective in the blanching of celery, endive (*Cichorium endivia*), witloof chicory (*C. intybus*), and a number of other vegetables. The cauliflower head as it appears in the market is etiolated, proliferated stem tissue. The difference between normal and etiolated leaves of rhubarb (*Rheum rhaponticum*) is shown in Figure 66.

Etiolated growth is in a sense parasitic; that is, it is made at the expense of food materials that have been manufactured elsewhere in the plant and perhaps accumulated in some storage organ, as root, stem, crown, bulb, or tuber. Consequently, if blanched celery stalks or hearts, or endive leaves, are to be large, there must first be large food reserves in their roots and crowns. Furthermore, etiolated growth is new growth, new tissue, and new plant organs, and therefore for rapid blanching both temperature and moisture conditions should be favorable for cell division.

PHOTOPERIODISM

Besides its influence on photosynthesis, which directly affects or even determines composition and which is more or less a mass effect of the product of intensity multiplied by the number of daylight hours, light exerts another, entirely different, influence on plants. This is a kind of directive influence on what they do, how they perform.

This influence is apparently due in some way to the length of daily exposure to light or the number of daylight hours and is known as the *photoperiodic influence* of light. Thus, if buckwheat seed is sown in the greenhouse in a northern latitude in early November, the plants will blossom in December when only a few inches high, more or less regardless of temperature, moisture, or fertility of soil; if their period of exposure to light is lengthened by four to six hours of artificial illumination, they may grow to be six or eight feet tall before blossoming. Ragweed is another short-day plant, blossoming and shedding pollen only when the day shortens to about thirteen or twelve and a half hours. Ordinary strawberry varieties, such as Dunlap and Premier, form runners freely, but no branch crowns or flower buds during the twelve- to sixteen-hour days of summer; during the twelve- to eleven-hour days of early fall they form branch crowns, few runners, and no flower buds; during the eleven- to nine-hour days of late fall they form still fewer runners, few branch crowns but do form flower buds freely. On the other hand, the everbearing varieties form flower buds and branch crowns during the long days of summer, as well as during the short days of fall, and hence blossom and develop fruit more or less continuously throughout the growing season.

When the number of hours between sunrise and sunset in a northern state reaches twelve or eleven and a half in autumn, a number of the *early* varieties of hardy chrysanthemums come into bloom; the later varieties do not blossom until the days are thirty, sixty, or even ninety minutes shorter. If, however, these same late varieties are grown farther south where the July and August days (the period for flower-bud differentiation in these plants) are shorter, they may blossom earlier than in the north. The poinsettia (*Poinsettia pulcherrima*) blossoms in mid-December in northern greenhouses, where it is a popular Christmas flower, because it is a short-day plant; it blossoms two weeks to a month later as grown outdoors in southern Florida, where the winter days are longer, because flower-bud initiation is delayed until late November or early December. Apparently many plants are adjusted as definitely and specifically to certain day lengths, or to certain ranges in day length, as they are to certain temperature ranges and moisture conditions. Their natural distribution, in turn, is determined by the length of day characteristics of the area in much the same

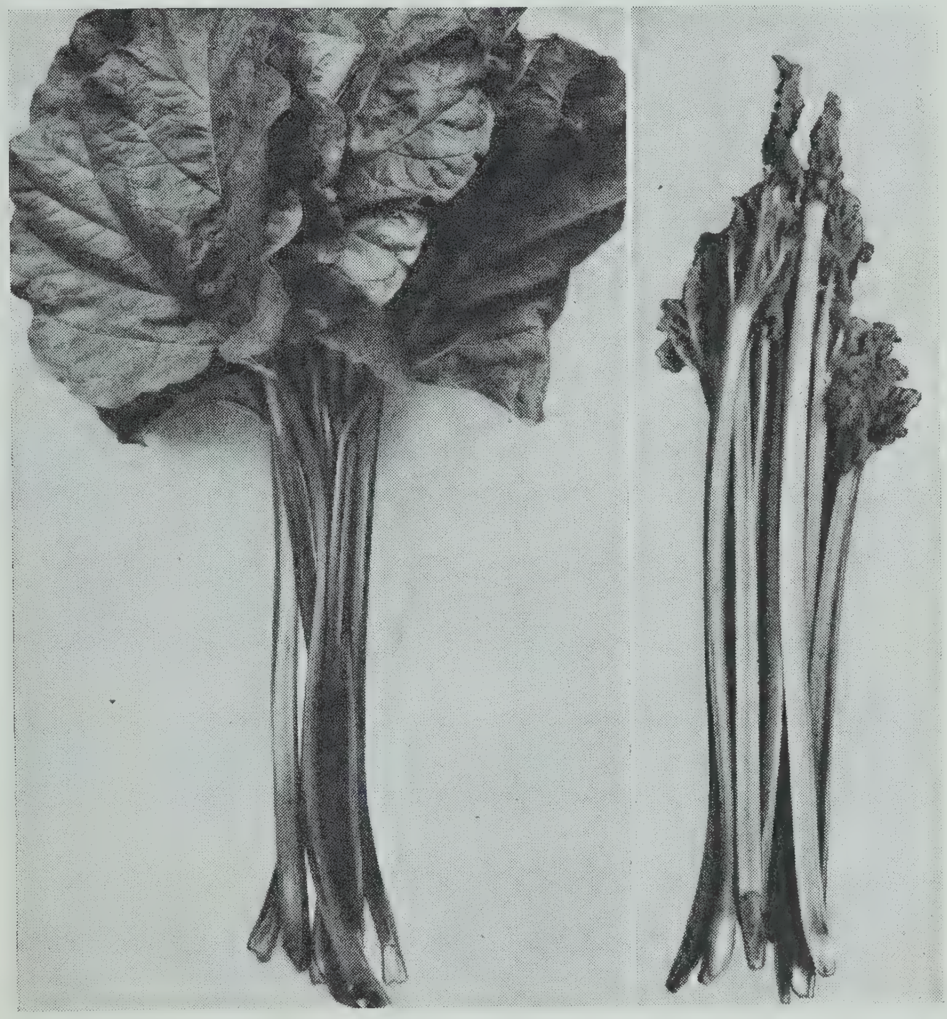

FIG. 66. Normal, outdoor-grown rhubarb leaves on the left; on the right etiolated or blanched leaves produced in the dark in a rhubarb-forcing house.

way as it is by seasonal changes in minimum, mean, and maximum temperatures. This often assumes importance in explaining the lack of adaptability of a crop plant or of a particular variety when taken to a new place where soil, temperature, and moisture conditions seem to be favorable, but the photoperiod is different.

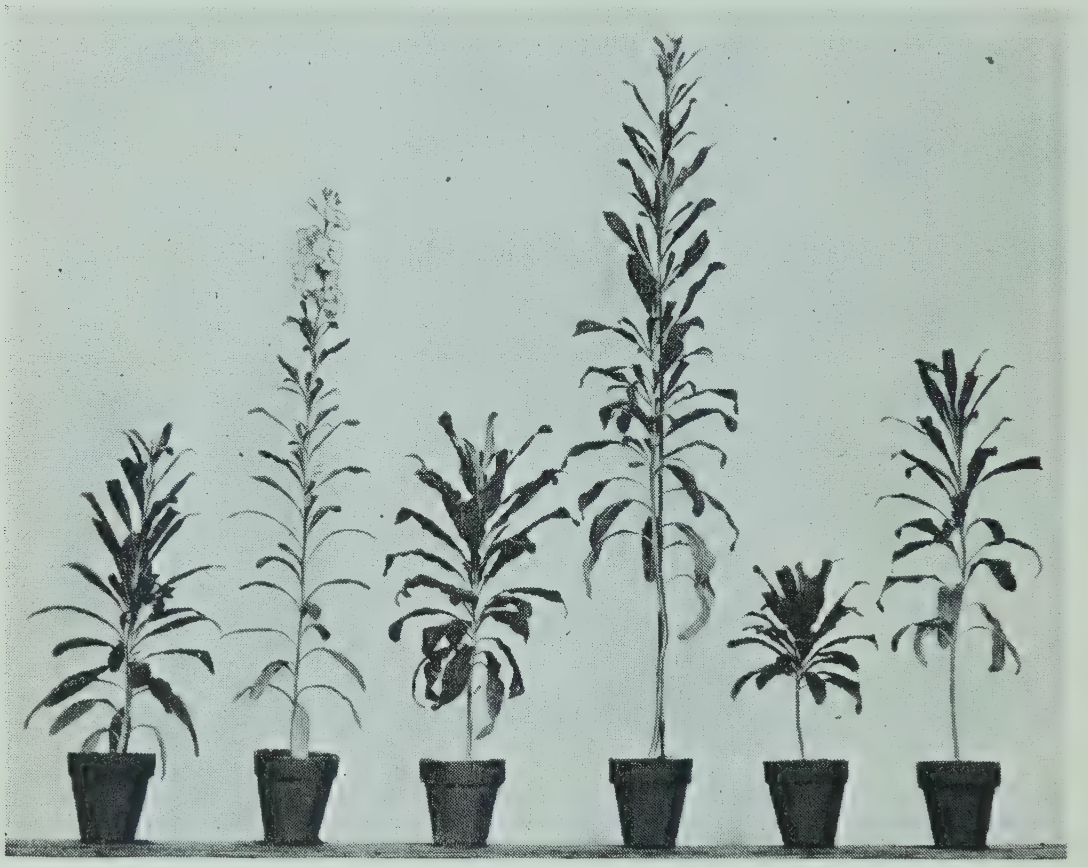

Fig. 67. Plants of the Christmas pink variety of stock (*Mathiola incana*) showing both photoperiodic and temperature influences. Courtesy of R. H. Roberts, Wisconsin Agricultural Experiment Station. Reading from left to right:

GROWING CONDITIONS	RESPONSES
Short day — cool temperature (55° F.)	Short internodes, flower buds formed
Long day — cool temperature	Long internodes, in flower
Short day — medium temperature (65° F.)	Short internodes, vegetative
Long day — medium temperature	Long internodes, flower buds formed
Short day — warm temperature (75° F.)	Very short internodes, vegetative
Long day — warm temperature	Short internodes, vegetative

In many instances photoperiodic effects are limited or greatly influenced by temperature. This is well brought out in Figure 67 which shows stock (*Mathiola incana*) plants of the Christmas pink variety grown under both short- and long-day exposures at cool, medium, and warm temperatures. The stock is generally classified as a long-day plant — that is, it forms flower buds and flowers under the influence of fairly long exposures to light. It is also a cool-season plant. When kept in a high temperature, it remains vegetative. High temperature has the effect of masking or inhibiting the characteristic influence of long days at a lower temperature. Figure 67 also serves to illustrate the influence of photoperiod on size and shape of leaves and general habit of growth, an influence hardly less pronounced than that on flower-bud formation and flowering.

The mechanism by which length of day operates to influence plant behavior so profoundly is not well understood, and there is little that any grower of field crops can do to change the characteristic behavior or response in respect to day length of the plant that he grows. However, the known facts regarding day-length influence help explain some of the peculiarities of many crop plants, and through information about these responses the grower may adjust plants to his environmental conditions through proper varietal selection. In the greenhouse shading and artificial lighting to modify the length of day have become regular practices in the culture of certain crops that have marked photoperiodic peculiarities.

It is significant that, though there must be a certain minimum light intensity for length of day to have its characteristic photoperiodic influences on plants of different kinds, that intensity is much lower than is the optimum for photosynthesis in the same plants. Indeed, in many instances light intensities so low as to be of little value for the photosynthetic process appear to be fully effective photoperiodically. Were this not the case, the greenhouse manager would hardly find it practicable to lengthen the daylight period for a number of his flowering plants in order to bring about "out-of-season" flowering.

Though many plants are characterized by a marked photoperiodism, many others appear not to be subject to length-of-day influences. Thus, the hibiscus (*Hibiscus rosa-sinensis*), greenhouse carnation (*Dianthus caryophyllus*), African violet (*Saintpaulia ionantha*), and the tomato form flower buds and flowers freely, regardless of length of day, when they attain a certain size. They are more or less "perpetual" flowering, in contrast to the kinds that have a distinct flowering season. In general, plants with a perpetual flowering habit are preferred for greenhouse culture and as house plants to those that flower only once in the course of a year.

PROBLEMS

1. Distinguish between photosynthesis and photoperiodism.

2. Would you expect to find any more or less direct relation between the responses of plants to length-of-day influences and their water content? Why?

3. Is the main objective in blanching horticultural products to (*a*) remove the green coloring matter from already formed tissues, (*b*) to promote the development of new tissues that don't have green coloring matter, or (*c*) regardless of coloring matter, to secure crisp succulent tissues?

4. Wherein lies the difference, if any, between blanching and bleaching?

5. Is it food products used for fresh salads or those that are eaten after cooking that are blanched? Why isn't the other group of food products blanched?

6. Would you expect the blanching process to be often used in the production of flower crops? Why?

7. Would you expect the artificial shortening or lengthening of the daylight period in order to secure photoperiodic effects to be most used by the producer of fruits, of flowers, or of vegetables? Why?

8. Would you expect the effect of a reduced light intensity on plants to be more like that of lower or of higher atmospheric humidity? Why?

9. Plants often wilt during the day and then regain their turgidity at night. Is this primarily a response to changes in light, in temperature, in soil moisture, or in atmospheric humidity? Explain fully.

10. Which would afford the greater protection of newly transplanted vegetable and flower plants from drying out — shading or watering? Explain.

11. Why are lath screens used over forest tree seed and seedling beds, more especially the evergreen species? Is it to reduce light intensity, to lower temperature, to check evaporation, or to reduce transpiration? Explain.

12. Are so-called *self-blanching* varieties of celery really self-blanching? If they are, how is the self-blanching to be explained? If they are not, what does the term really mean as applied to them?

CHAPTER VIII

PLANT NUTRIENTS AS LIMITING FACTORS

FOR MANY years textbooks of plant physiology listed ten elements as essential for the growth of plants — oxygen, hydrogen, carbon, nitrogen, potassium, phosphorus, calcium, magnesium, sulphur, and iron. The plant obtains the first two, oxygen and hydrogen, from the water that it absorbs from the soil, since these elements are the constituents of water. The third, carbon, is obtained from the carbon dioxide of the air. The other seven are absorbed in dilute solution from the soil.

Ordinarily oxygen and hydrogen, as elements, are not thought of as limiting factors for growth, though the supply of water from which they are obtained often is a limiting factor. Similarly, carbon is not commonly regarded as a limiting factor for growth since the above-ground parts of plants are continually bathed in an atmosphere containing a small but fairly constant percentage of carbon dioxide (three fourths of 1 per cent, the rest consisting mainly of nitrogen and oxygen) from which it is obtained. We have just seen, however, that under conditions of drought carbon may become a limiting factor through the closing of the stomata and the consequent exclusion of carbon dioxide from the interior of the leaf where it can be absorbed and used. In reality, therefore, water supply is the limiting factor for carbon intake, just as it is for the oxygen and hydrogen supply. Though nitrogen constitutes nearly four fifths of the air, higher plants cannot directly utilize the supply and must obtain their nitrogen in the form of certain nitrogenous compounds from the soil. Nitrogen, then, along with the other six mineral elements, is obtained from the soil solution. If any one of these elements is not found in a particular soil, or if it is present in inadequate quantities, or even in adequate amounts but not in forms in which the plants can absorb it, growth is limited. Any one of these seven mineral elements which the plant obtains from the soil may become a limiting factor, and in reality each and every one has been found to be limiting in one place or another. Practically, however, nitrogen, potassium, and phosphorus are more frequently limiting factors than are the other four supplied by the soil.

During the last two decades it has been found that a number of elements besides these ten are necessary for normal plant growth. This list has been steadily growing and now includes manganese, copper, zinc, and boron. Because only extremely small quantities of these elements are required, they are known as *minor* or *trace* elements. They are, nevertheless, limiting factors as truly as are any of the "big" ten. They may be compared with the platinum points in the distributor of an automobile; these points weigh less than a hundredth of an ounce whereas the car weighs from a ton and a half to two tons. In terms of percentage of total car weight the points are almost infinitesimal; yet without them the car will not run.

Still other mineral elements are absorbed by the roots from the soil solution and may be found in different parts of the plant, sometimes in considerable amounts. Among the more common of these are sodium, silicon, aluminum, and chlorine, though there are many others. They are apparently harmless, if present only in moderate amounts and are simply tolerated by the plant rather than utilized. They form what is often spoken of as the plant's "indifferent" ash.

NITROGEN

Of all the nutrient elements nitrogen is most frequently the limiting factor. This is not so much because the total supply in the soil is inadequate as because most of this supply is in such a form that the plant cannot obtain it. The main supply of nitrogen in the soil is in the form of slowly decomposing organic matter, and the nitrogenous compounds (proteins and their immediate disintegration products) of this organic matter are not directly available to the plant. Before they can be freely absorbed by the roots, they must be completely broken down by bacterial action — first changed to amino acids, then to ammonia, then to nitrites, and finally further changed into nitrates. Certain kinds of bacteria are responsible for the first stages of their decomposition, others for later stages. The final change from nitrites to nitrates is called *nitrification*. Nitrates are readily soluble in water, and the plant can absorb them; likewise they may be leached from the soil through the drainage water resulting from excessive rainfall or irrigation.

Bacterial decomposition of organic nitrogenous compounds, as well as their later nitrification, is inhibited by low temperature and drought. In northern sections, therefore, the soil is practically devoid of nitrates during the late fall, winter, and early spring months, and the supply during portions of the growing season may be much limited by unfavorable environmental conditions. This is especially likely to be the case in the spring while the soil is still cold, and consequently early growth, particularly of cool-season annuals, is likely to be limited because of an inadequate nitrogen supply. Actually most soils have an abundance of nitrogen at that period, but it is not available to the plant. Therefore, it is the practice with many crop plants — especially those where vigorous growth early in the season is desirable — to provide the plants at or soon after seeding or setting with a quickly available nitrogen supply, often in the form of nitrate of soda or ammonium sulphate which they can immediately absorb and use. This is especially important with pasture crops, early vegetables, and many of the fruits. With other crops the greatest demand for nitrogen comes a little later in the season when bacterial activity in the soil is well able to provide an adequate supply. Nitrogenous fertilizers are less important — unless the supply of organic matter in the soil, from which the nitrates are formed, is so small that it needs to be supplemented. In southern sections temperature is not likely to be a limiting factor to nitrate formation, but at certain seasons heavy rainfall, especially where the soil is light, may leach nitrates away as fast as they are formed. In arid or semi-arid sections, both in the North and South, nitrate formation may be checked because of lack of moisture, but the nitrate that is formed will not be leached away, and in reality soils in these areas are generally much better supplied with nitrate than are those of humid sections.

What the situation as a whole amounts to may be expressed in this way: There is a supply of nitrogen in every soil, often adequate for the requirements of crop plants for many years; however, in many, if not most, areas it is both figuratively and literally in cold or in dry storage during a part of the year, locked up so that the plant cannot get it and so that it cannot be leached away.

Its change into a form available to the plant — its release from storage — comes only during the late spring, summer, and early fall, and during that period nitrification may be fairly rapid. If crop plants utilize the nitrogen then, well and good; if not, it is leached away and lost. Good farming provides rapidly growing crop plants with a supply that is being made available by natural agencies as rapidly as they are able to utilize it; it also provides a supplemental supply when nitrogen is needed by the plant but little or none is available. Indeed, much of the success in raising many crops depends upon the skill with which the farmer judges nitrogen requirements and then sees to it that those requirements are properly met.

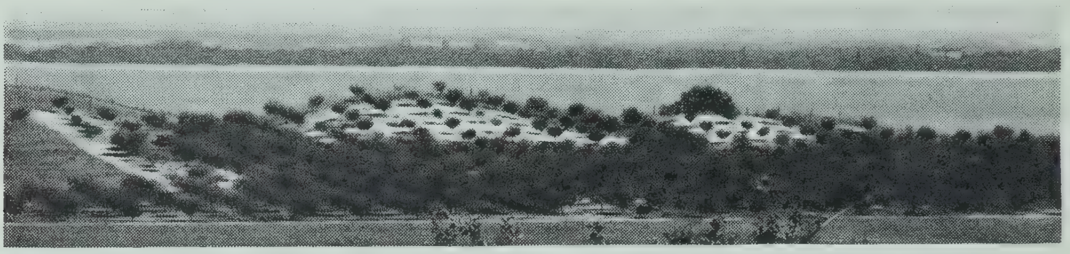

Fig. 68. An orchard view, overlooking Grand Traverse Bay in northern Michigan. Note the small size of the trees on the hill tops where the surface soil has been worn thin by erosion, as compared with their size at the foot of the slopes.

The annual crops that are in the small seedling stage during the early part of the growing season do not require much nitrogen at that time, for they are not making a large amount of new growth. A little later, however, they require much more, and this demand continues throughout the season, as with tomatoes, peppers, and petunias, or tapers off after midseason or toward its end, as with beans and peas, depending on maturing season of the crop, for current nitrogen requirement more or less closely parallels new growth. On the other hand, many woody, herbaceous perennial and biennial plants which make most of the new growth of the season comparatively early — for example, the apple, gooseberry, asparagus, peony, larkspur — have a large early-season demand for nitrogen, as compared with that required in midsummer and fall. This must be provided either from a supply accumulated in roots, crown, or stems the season before or from a supply made available in spring and early summer. It is for this reason that relatively heavy early spring or fall applications of quickly available nitrogenous fertilizers have become rather standard practice in many fruit plantations and that similar applications are made to many herbaceous perennials in late summer and early fall.

In general, a deficiency in many nutrient elements results first in a retardation and finally in a complete cessation of growth. This general deficiency symptom may be accompanied by more specific or differentiating symptoms in the case of certain nutrients. Thus, if the supply of available nitrogen is insufficient for normal growth, the leaves may acquire a rather uniform pale green or yellowish green cast, as contrasted with a rich dark green for plants well supplied with nitrogen. The appearance of these leaf symptoms is soon followed by a slowing down in vegetative growth, and in extreme cases by a dwarfing or stunting of the plant. This is well illustrated in Figures 68 and 69 which show the influence of "good" and "poor" soil nutrient conditions on the growth of cherry trees and blueberry plants, the main difference in the soils being the available nitrogen supply. An overabundant supply of available nitrogen results in large, dark green leaves, and very vigorous vegetative growth often at the expense of flower and fruit production — a condition sometimes referred to in the case of annual plants and vines as "running to

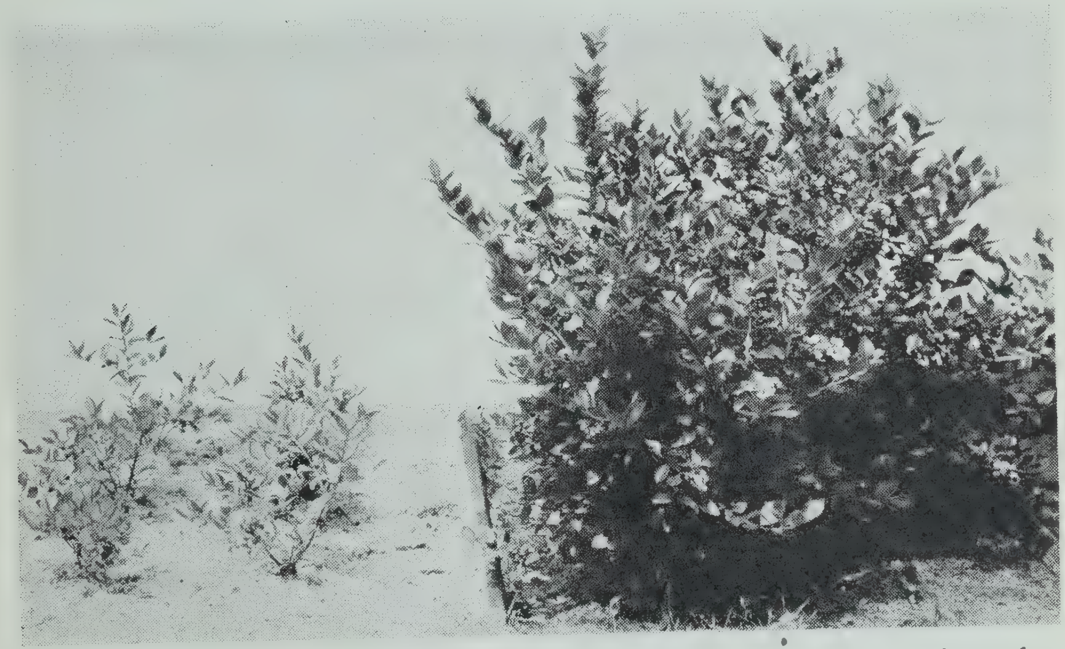

Fig. 69. On the right are three-year-old blueberry plants growing in the surface layer, or A horizon, of Saugatuck sand, a soil type suited to their culture. On the left are plants of the same age growing in the B horizon or subsoil of the same soil type. In this instance the main difference between the two layers is in organic matter and nitrogen supply.

vine." Such overvigorous plants are slow to acquire maturity in the fall.

Plants belonging to the legume family, such as the bean, are able to obtain nitrogen from the air present in the soil through the agency of certain types of bacteria that form nodules on their roots.

POTASSIUM

Unlike nitrogen, most of the potassium supply in the soil is in its basic mineral substance, rather than in decaying organic matter. It is mainly in the form of solid particles that are very slowly soluble and even that portion that is soluble is not subject to any considerable leaching, except in soils of light texture. Most soils contain relatively large quantities of potash (for instance, it has been estimated that the average prairie soils of Illinois contain enough potash in their surface six feet, which may be penetrated by the roots of most crop plants, to grow 5,000 crops of corn), but on account of its very low solubility, supplemental applications are desirable in many instances with certain crops. Thus the problem of potassium fertilization, like that of nitrogen, is one of supplementing the readily available supply rather than replenishing the total supply. Furthermore, in view of the fact that there is little leaching of potassium, the application may be made at almost any season of the year, and special timing of potassium applications is far less important than with applications of nitrogen.

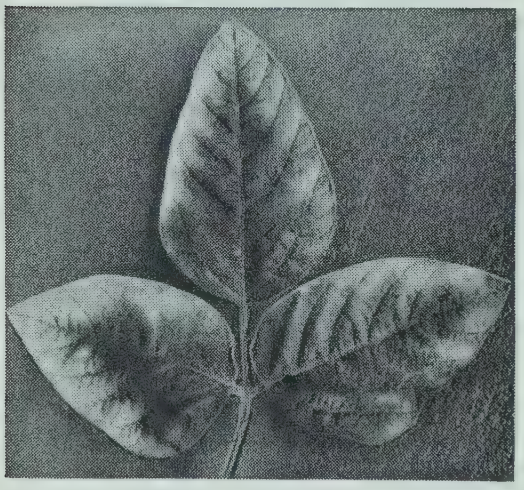

Fig. 70. A bean leaf showing chlorosis due to potash deficiency.

Symptoms of potassium starvation are less distinctive than those of nitrogen deficiency. In addition to stunting, which eventually takes place, marked potash deficiency may be indicated by bronzing of the foliage in some plants, by mottling or chlorosis (see Figure 70) in others, by leaf scorch or burn at the edges or in scattered areas in still others, and occasionally by other symptoms.

PHOSPHORUS

The absolute amounts of phosphorus required by plants are relatively small, as compared with those of a number of the other elements — a tenth to a fifth as much as of nitrogen or potassium or calcium — and most soils contain at least moderate amounts. However, most of the supply is held by the soil in the form of insoluble phosphates so that the portion that is readily available to the plants is most frequently of all the nutrients, except for nitrogen, a limiting factor for growth. Most fertilizer recommendations, except those for fruit crops, include phosphorus. Though actual crop requirements are small — about three pounds of actual phosphorus are removed from an acre of land by a 400-bushel apple crop, and about the same amount by a 300-bushel crop of potatoes. Though little leaches away, the quantities applied are often considerably larger than depletion by the crop would suggest as necessary. With many crops liberal applications of phosphorus are very effective in increasing yields and promoting early maturity.

Symptoms of phosphorus deficiency, other than a dwarfing associated with a deficiency of any one of several of the other nutrients, are none too distinctive. Usually the leaves remain dark green, and thus differentiation from nitrogen deficiency is easy. The new growth is rather spindly, stiff, and brittle. In the tomato and some other crops, phosphorus deficiency may be accompanied by the development of a reddish purple color on the under sides of the leaves.

CALCIUM

Lime usually constitutes a relatively large percentage of the ash of plants and apparently is required in considerable quantities for normal growth. Full-sized trees may take up as much as 60 to 100 pounds per acre per year for fruit, wood, roots, and leaves, and herbaceous crops may require as much, but fully half of these amounts are returned to the soil sooner or later in the form of crop residues.

Few soils are so deficient in calcium that they are unable to supply crop plants with their requirements of this element. On the other hand, soil reaction — a matter to be discussed in some detail later — is greatly influenced by its calcium content, and the amount of calcium likewise exerts an important influence on the texture of many soils. Consequently, the liming of many soils for certain crops is a common practice.

MAGNESIUM

Though magnesium resembles calcium in some of its properties and to a certain extent may be used in place of calcium as a soil amendment, it serves a different function in the economy of plant life. It is required in somewhat smaller quantities than is calcium; the supply in most soils is adequate to meet these requirements, and under most field conditions magnesium content is not a limiting factor. Under artificially controlled conditions of nutrient supply, magnesium deficiency leads to development of a chlorotic condition (described in connection with iron deficiency).

SULPHUR

Sulphur is taken up by the plant in even smaller amounts than is phosphorus. Most soils contain ample quantities of sulphur for crop production for many years, and contrary to what is true of calcium, magnesium, potassium, phosphorus, and iron, appreciable amounts are added to the soil each year dissolved in rain water. This is in the form of sulphuric or sulphurous acid formed by combination of the moisture in the air with sulphur dioxide that results from the burning of coal and other fuels. Seldom is it necessary to apply sulphur-containing fertilizers to soils in order to meet their crop requirements, though in sections of the Pacific Coast yields of alfalfa, cabbage, and a number of other crops requiring relatively large quantities of this element have been greatly increased by such applications.

Applications of sulphur are sometimes made to alkaline soils to reduce their alkalinity or to mildly acid soils to increase their acidity. As a matter of fact, sulphur is probably used much more frequently and in larger quantities for the purpose of changing soil reaction than for the purpose of adding a nutrient.

IRON

Iron is required by plants only in very small amounts — a ton of lettuce or spinach or celery contains only about three ounces and a 500-bushel crop of apples removes only about one pound from an acre of soil. Most agricultural soils are abundantly supplied with iron; in a few soils, as some of those in the Hawaiian Islands devoted to pineapple culture, compounds of iron constitute over half the soil substance. Furthermore, in most soils the iron is readily available to plants — at least in the quantities required.

Nevertheless, it is not uncommon to find soils in which plants have difficulty in obtaining the small amount of iron that they require, and paradoxically, it is often in soils of the highest iron content that plants have the most difficulty. This is because the availability of iron is greatly influenced by soil reaction and lime content — the higher the lime content and more basic the reaction, the less available the iron.

Plants unable to obtain sufficient quantities of iron become chlorotic — that is, their leaves, especially the newer growth, become pale yellow or white in color owing to their failure to develop chlorophyll. This condition is illustrated in Figure 70, though the chlorosis shown there was induced by a potash deficiency. These chlorotic leaves are unable to manufacture carbohydrates, and if the condition is severe, it may lead to starvation, even though there is available an abundance of all the other mineral nutrients. Chlorosis due to iron deficiency may be cured or prevented by supplying the plants with iron in some available form, sometimes by applying iron sulphate or iron citrate directly to the soil, sometimes by spraying the plants themselves with dilute solutions of these materials. Sometimes it is prevented or cured by boring holes in the trunks or branches of trees and placing ferrous salts in them to be taken up by the rising sap currents or even, in some instances, by driving nails in their trunks.

MINOR OR TRACE ELEMENTS

Among the so-called *minor* or *trace* nutrient elements manganese was the first to be shown definitely as essential to growth. Symptoms of manganese deficiency include an etiolated type of leaf and shoot development accompanied by more or less spotting of the leaves with gray or brown areas of dead tissue. Sometimes the veins of the etiolated leaves remain green. Though not exactly a common and not often a serious deficiency, it is rather widespread, being found in many different crop plants and in many different sections — for example, on citrus trees in Florida and on tobacco in Kentucky. Applications of manganese sulphate are sometimes made to neutral or alkaline muck soils, partly to make them less alkaline or more acid, partly to supplement the small natural supply of manganese.

Copper is found in most soils only in very small amounts, but these are ample for plant growth in most instances. It has been found, however, that in some of the highly organic soils, peats, and mucks, the quantity present is so extremely small that it becomes a limiting factor. Initial stages or pre-stages of copper deficiency in citrus trees, in which this disorder has been reported, resemble those associated with a surplus of nitrates, but are promptly followed by dieback of twigs and younger branches. In Michigan onion crops raised on muck soil are often greatly benefited by applications of copper sulphate, yields being higher and bulb

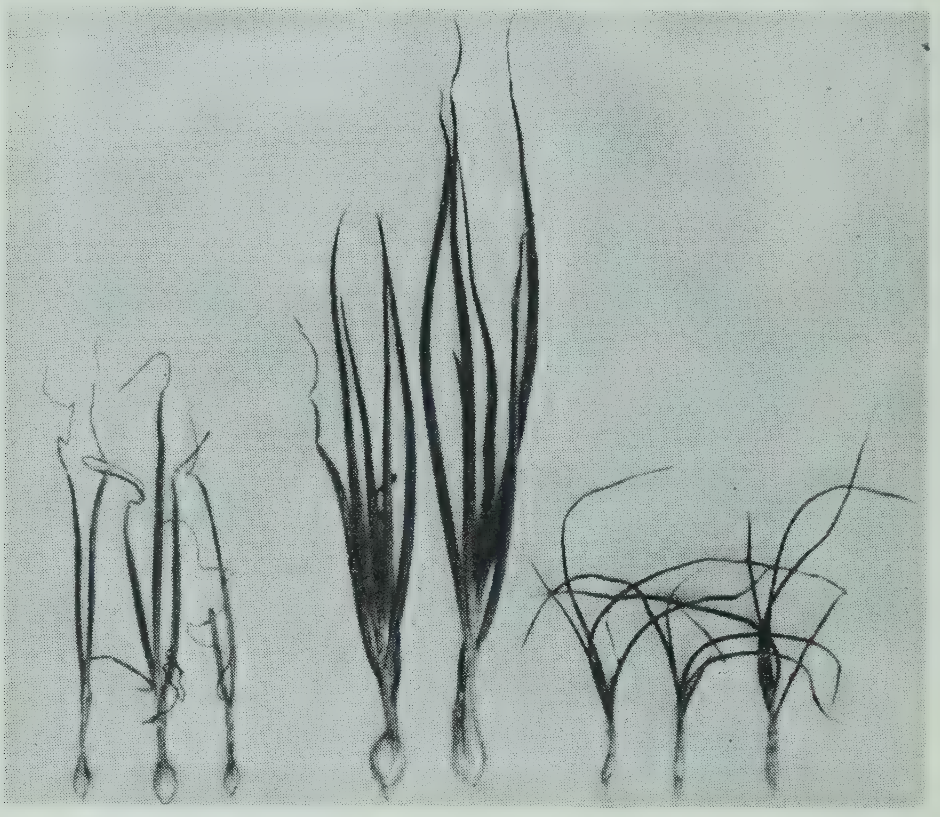

FIG. 71. These onions, grown on a muck soil, were all sown the same day and fertilized uniformly with phosphate and potash. The four on the left were from an area on the plots where the soil reaction was slightly acid (pH 6.0); the four on the right were from a nearby area where the reaction was slightly alkaline (pH 7.8). The three at the left end received no copper. The fourth from the left came from a section of the plot treated with copper sulphate at the rate of fifty pounds to the acre. The three at the extreme right illustrate the typical growth response of onions to an alkaline soil reaction. The fourth onion from the right came from a section of the plot on which the reaction had been changed from alkaline to acid by an application of sulphur.

color being improved. Some of the responses shown by onions growing on muck soil to applications of sulphur and copper are illustrated in Figure 71.

Only very recently has zinc been established as an essential nutrient element, and so far as present evidence goes, zinc deficiencies are not of common occurrence. In the Pacific Coast states, however, limited zinc supply has been established as a cause of a rather common deciduous tree disorder known as "little leaf" or rosette. It may be prevented or remedied by making applications of zinc salts to the soil, or even by driving zinc nails into the trunks of the trees. In California the same disorder on citrus fruits is often called "mottle leaf" and in Florida "frenching."

Boron is the most recent addition to the list of essential plant nutrients, but the areas and list of crops where and with which it is being found to be a limiting factor is steadily expanding. Its lack has been found responsible for a reduced growth and a blackening of the interior of the roots of a number of root crops in many of the northeastern states and Canadian provinces. This is especially important in beets and rutabagas. Deficiency leads to dwarfing, deformity, and darkening of cauliflower heads. In celery its lack leads to a disorder known as "cracked stem"; in apples to "corky core," in citrus fruits to dieback, gumming, and various other symptoms. Considerable care needs to be exercised in making applications of boron-containing compounds to soils for even rather small quantities sometimes prove toxic.

Growth-Promoting Substances or Hormones. Both the major and trace elements that have just been discussed serve to promote growth and the same may be said of the substances or compounds of which they form a part in the soil or in the nutrient solution. If any one is deficient in amount or is in an unavailable form, the deficiency becomes a limiting factor.

There is a rapidly accumulating body of evidence that, besides these commonly recognized nutrient elements and substances, there are certain specific substances or compounds that may have an influence on growth seemingly out of all proportion to the quantities in which they are found. Thus extremely small amounts of naphthalene acetic acid greatly stimulates root formation in cuttings of many kinds of plants. Other compounds promote callus formation or cell division and proliferation in certain tissues; others are effective in causing unpollinated flowers to set and develop into fruits (usually seedless); still others delay the maturing and falling of leaves, flowers, or fruits. This group of substances includes: (1) certain compounds that have been produced synthetically in the laboratory and whose chemical formulae are known, (2) others that appear to be products derived from the natural disintegration of plant and animal residues in the soil, (3) still others that appear to be the result of the normal metabolic processes of the living plant. They are generally referred to as growth-promoting substances or *hormones*. Some appear to be very specific in occurrence or in action — that is, they are found only in certain parts of certain plants at certain times or they exhibit only a specific growth-promoting influence under rather specific conditions. Others are more general, being able to stimulate growth in many different parts of plants of many kinds. Though considered here along with nutrients, their role may perhaps be more properly regarded as that of *activators*.

MAKING FERTILIZER APPLICATIONS

In many, if not most, instances in general field practice a single nutrient element is likely to be the limiting factor at a given time and with a given crop. With another crop on the same soil a different element may be the limiting factor, for different crops have different nutrient requirements and different feeding habits. Furthermore, for a certain crop available nitrogen may be the limiting factor in May whereas phosphorus or boron may be limiting in August and September. Deficiency symptoms are sometimes deceptive, especially when two or more elements may be at a dangerously low level at the same time or when insect or disease attack or some other environmental factor may be resulting in abnormal development. Consequently, in actual field practice mixed or "complete" fertilizers carrying several of the nutrient elements rather than those carrying a single one, are commonly used. All of the so-called "complete" fertilizers carry nitrogen, potassium, and phosphorus, the three elements that are most commonly present in insufficient amounts for optimum growth. In reality they are not complete, for most of them do not carry the other four essential major elements, to say nothing of the essential minor elements. The proportions of the several nutrient elements in these "complete" fertilizers vary greatly — so that if a farmer believes that for a certain crop on a certain soil relatively more phosphorus is required than for a different crop on a different soil he can obtain a fertilizer with a higher, or lower, phosphorus content, as the case may be.

Farm manures carry all the essential nutrient elements, both major and minor, and so are *complete* in a truer sense than are the "complete" commercial fertilizers. However, manures are usually more or less unbalanced in that they often carry a larger percentage of nitrogen and potash and lower percentages of some of the other nutrients than would be applied in the form of commercial fertilizers best suited to the requirements of the crop in question. In addition to being complete fertilizers, farm manures benefit the soil by improving its physical condition — water-absorbing capacity, water retention, porosity, aeration, etc. Sometimes these influences on physical condition are more important in contributing to the growth and productivity of the plants than are the nutrients that they add to the soil.

The supply of any nutrient may become depleted at any time during the growing season, depending on rate of solubility, bacterial activity in the soil, leaching by rains, withdrawal by crop plants, and many other factors. Limited quantities of available nitrogen may slow down growth in June, whereas with the same plants limited quantities of magnesium or iron may lead to disorders in August. Not only because it is sometimes impossible to detect deficiency symptoms before the deficiency has become a serious matter but because it is impracticable to make repeated fertilizer applications as the season progresses, the usual procedure is to apply rather generous amounts before seeding or planting, sufficient to take care of all anticipated requirements. Except for nitrogen the surplus amounts are not likely to be leached away and the losses of that element amount to less than the value of its assurance that the supply of all nutrient elements is adequate. Good fertilizer practice, therefore, means applying more than will be actually required by the plants. With intensively grown plants in gardens and greenhouses light applications, repeated at intervals of one or two months, are often preferable to a single heavier application early in the season.

PROBLEMS

1. Which of the nutrient elements depends on bacterial activity to make it available to plants?
2. What is the distinction between a plant nutrient and a plant food?
3. In what respect is a so-called *minor* element minor?
4. Would you expect the largest nitrate supply where there is the largest supply of humus, or would you expect it to be more or less independent of the humus supply? Explain.
5. Under what conditions and in what sections would you expect the humus supply of the soil to last the longest, and under what conditions and in what sections would you expect it to be the shortest lived? Why?
6. The term *burning out* is often applied to the humus supply of the soil. Explain what is meant.
7. Do you think it good horticultural practice to attempt to maintain a large or a rather small humus supply in the soil? Why?
8. Peats and mucks are soils consisting almost entirely of organic matter in various stages of decomposition. What are the nutrient elements you would expect to be required most often and in largest quantities by such soils and which ones would be least likely to be a limiting factor?

CHAPTER IX

WATER AND NUTRIENT INTAKE, TRANSLOCATION, AND UTILIZATION

THE several mineral nutrients which the plant obtains from the soil are for the most part present not as chemical elements but combined chemically with certain other elements or substances. Thus, we do not find pure calcium but rather calcium combined with chlorine to form calcium chloride, combined with sulphur and oxygen to form calcium sulphate or gypsum, or perhaps combined with carbon dioxide to form calcium carbonate or limestone. Most of these substances are in the form of irregularly shaped solid particles of varying size, which, together with non-nutrient mineral compounds such as silica, make up the body of the soil. Some go into solution in water fairly readily, others more slowly, still others hardly at all — though most substances commonly thought of as insoluble, even glass, are to some slight degree soluble in water. Thus, soil "water" is not just water but rather a dilute solution of the many substances found in the soil, containing higher concentrations of the more soluble ingredients and lower concentrations of others. For instance, 100 pounds of soil "water" may contain at a specified time an ounce of sodium nitrate, two ounces of calcium chloride, three ounces of potassium sulphate, a half ounce of magnesium carbonate, and several ounces, all told, of a number of other materials, or this amount may contain less than an ounce of all these materials. The solubility of certain materials may be considerably increased by secretions of plant roots, and so it may be said that the plant in obtaining its nutrients assumes an active, rather than just a passive, role.

AVAILABILITY

It is necessary first that nutrient materials be in solution before the plant can obtain them. It is also necessary that they be present in certain forms, that is, in certain combinations. Thus, it has already been mentioned that nitrogen is absorbed principally in the form of nitrates — nitrites, ammonia, proteins, not being readily available to the plant and some of them being toxic to certain kinds. Availability, however, is often a characteristic or function not so much of a particular chemical compound as of the plant itself. By this is meant that in a certain soil in which, say, potassium or boron is present in certain forms, that is, in certain definite chemical combinations, one plant may be able to get all it requires for normal growth, while another plant is dwarfed or fails to fruit or suffers in some other way for its lack. Thus, in certain soils in Michigan sugar beets and turnips grow to only half or two thirds their normal size, are black hearted and practically worthless because of boron deficiency, while on the same soils

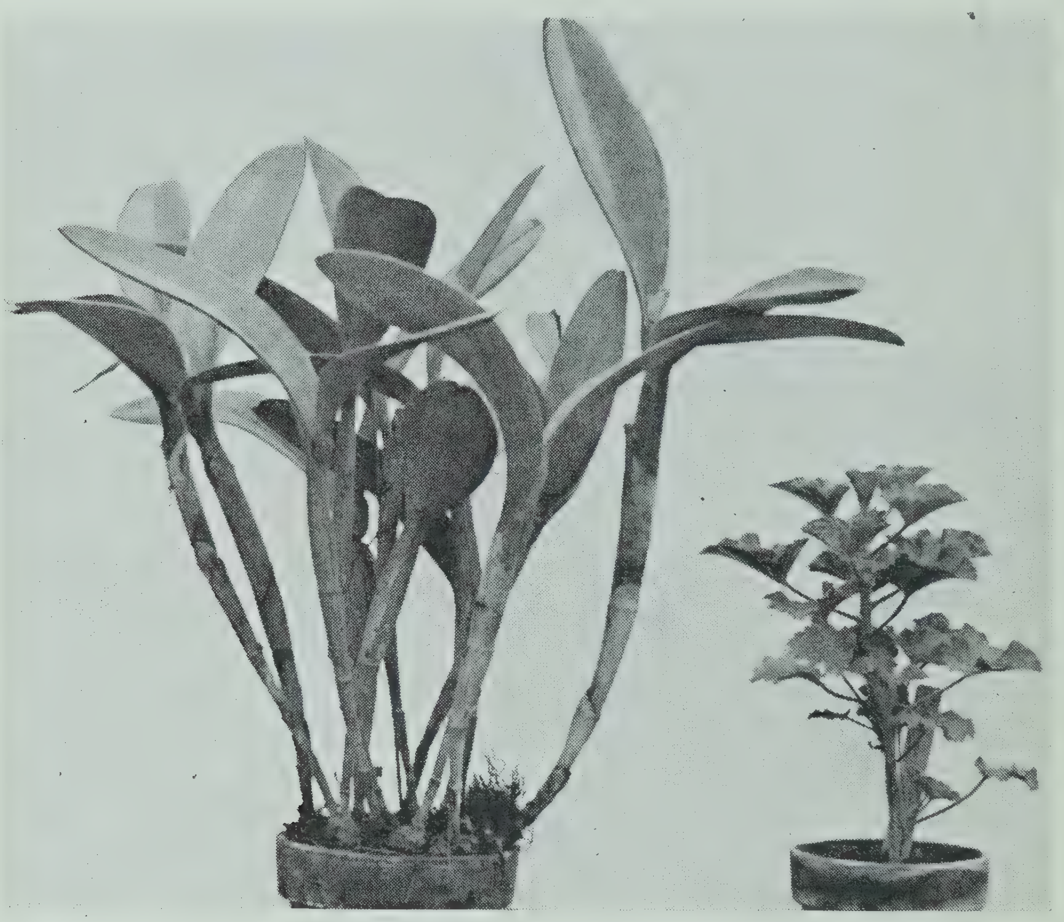

FIG. 72. On the left a thrifty vigorous plant of a *Cattleya-Laelia* hybrid that had not been repotted for over two years. On the right a *Pelargonium* plant that, though shifted to its pot only six weeks before, had stopped growing because it was no longer able to obtain sufficient nutrients from the soil to make new vegetative growth. This illustrates the marked difference between plants in their ability to grow and thrive on a limited volume of soil and a limited nutrient supply.

potatoes and carrots, which require fully as much boron, produce large crops of first quality. The boron supply in the soil is not changed by the crops growing on it; potatoes and carrots are simply more efficient boron-feeders. Figures 72 and 73 illustrate differences in the apparent feeding ability of several ornamentals. Constant observation and study of his own conditions together with proper recognition of these differences in the foraging ability of various crop plants will go far toward reducing the farmer's fertilizer bill and toward enabling him to make the best use of his land.

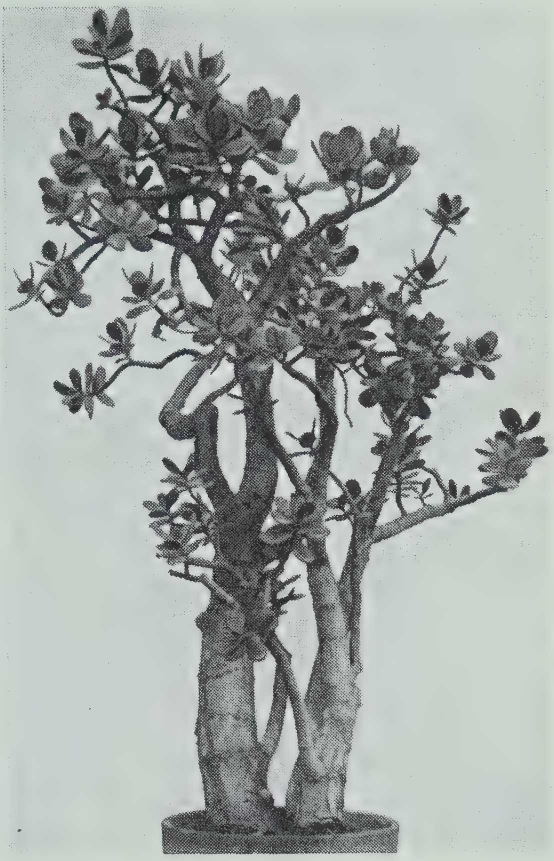

Fig. 73. An old plant of *Crassula arborescens* that had been growing in this same pot for several years. Though very large for the volume of soil to which its roots were confined, it was making a moderate amount of new growth, illustrating the ability of some plants to thrive on a very restricted nutrient supply with a very restricted root system.

ABSORPTION

Absorption of both water and nutrients takes place through the epidermal layer of the younger portions of the roots and through the root hairs. It is effected through a process known as *osmosis*, which is essentially an interchange of materials between two solutions separated by a semipermeable membrane, so that eventually an equilibrium between the two is established — that is to say, the concentration of individual substances on both sides of the membrane tends to become essentially the same. The walls, together with the layer of living protoplasm lining them, of the epidermis and root hairs constitute the semipermeable membrane, separating the soil water and the nutrients it contains in solution from the contents of the vacuoles (which consist of water with small quantities of these same nutrient materials, together with certain organic substances such as sugar). If these epidermal cells and root hairs were nonliving things constructed in the laboratory to resemble living cells and then placed in the soil, it would be a very short time before diffusion would bring about an equilibrium between what they contained in solution and what was in solution in the soil water about them. Something approaching this takes place in the live epidermal cells of young roots and root hairs, but with two major modifications: (1) The cell wall with its lining of living protoplasm is so constructed that, though it allows water and nutrient materials to enter rather freely, their flow and likewise that of solutes other than nutrients, in the opposite direction does not take place anywhere near so readily. (2) This flow is always inward (from the soil into the root) rather than sometimes in one direction and sometimes in the other, because the *living* plant is capable of so altering the composition of its cell sap that the concentration of specific or individual solutes within is kept lower than is the concentration without, such a difference in concentration being requisite to any flow of materials through a membrane from one side to the other. This alteration of composition is brought about in two ways: (*a*) As concentrations within the cell sap approximating those without the plant are approached through inward passage of the solutes, the solutes in question in turn go through other membranes into adjacent cells which have lower concentrations of these particular solutes and thus into the conducting system of the plant. Inward and thence upward translocation is thus effected through a gradient in concentration from relatively high in the absorbing cells of the root to relatively low in the cells elsewhere in the plant where the materials in question are being used. (*b*) This gradient is kept more or less constant through the utilization of the nutrients in the tops and other parts of the plant, utilization involving withdrawing them from solution, combining them with other substances, and building them into the more or less insoluble storage or food products or the permanent framework of the plant. Rate of utilization, therefore, is seen to be the factor which determines rate of absorption, in the presence of an abundant supply. On the other hand, in the presence of relatively limited supplies of nutrients and of water, rate of intake becomes the limiting factor to rate of utilization. One process is always serving as a check upon the other.

The statements that have just been made furnish an explanation of another plant characteristic often referred to by the term *selective absorption*. If a plant takes up some nutrient material only as fast as it utilizes it, and if it can utilize that particular nutrient only half or a third as rapidly as some other material, it necessarily follows that it will absorb only half or a third as much within a given period. This is true even though that particular material is available in the soil solution in amounts equal to or several times greater than the materials of which it uses more. Mineral nutrients aren't just "swept into" the plant along with water. For the most part, the plant takes in water only when and as it needs it. With this water it permits the absorption of various mineral nutrients, as it uses them. It isn't just a physical process, with the plant a bystander or onlooker. It is a physiological process in which the plant itself plays a part, in fact, a determining part. Since absorption rate is seen to be more or less independent of concentration in the soil solution, any undue effort to provide a plant or crop with a nutrient supply, through the use of fertilizer, that in its composition very closely resembles the ash analysis of the plant is hardly warranted. Rather the procedure should be to supply ample amounts of all the nutrients required for growth, leaving to the plant the matter of intake in the proportions in which they are required.

Absorption of both water and mineral nutrients has just been described and explained as due to osmosis, and their movement from one cell into another and then into the vascular or conducting cells or tubes is due to the same process. It has been implied that their subsequent flow in the tubular cells and rise in the vascular system of the plant through stem to leaves is similarly due to a continuation of the same process. As a matter of fact, movement of both water and mineral nutrients to all parts of the plant is due in part to this process. It is aided by another factor, suction force coupled with the tensile strength of a column of liquid. The water, with its dissolved substances, in the tubes or ducts of the vascular system of the plant is essentially a continuous liquid column. As such it possesses the tensile strength of a similar liquid column in a capillary or other tube. This means that a lifting force of some fifteen atmospheres would have to be applied at the top in order to break the column. This is greater than the suction force or pull exerted by the drying effects of the air circulating in the spongy parenchyma of the leaves. Consequently the water columns are not broken, but the suction force or pull on them at their tops keeps their water moving upward and outward. The rise of water in plants, therefore, is due more to the pull exerted by the leaves than to any push given it by the roots.

CONCENTRATION OF NUTRIENT AND OTHER SUBSTANCES IN THE SOIL

As a general rule, nutrient and other materials dissolved in the soil water are in very dilute solutions. Thus, levels of nitrates of 50 to 100 parts per million are considered high and levels of 10 to 20 or less are far more common; levels of salts of some of the other "big ten" nutrient elements such as potassium and magnesium may sometimes be as low as 2 or 3 parts per million in the soil solution; those of the minor elements may be much lower. Total materials in solution are likely to amount to less than 1,000 parts per million. Still the plants are able to absorb from these dilute solutions, though somewhat less rapidly than from stronger solutions. These very dilute solutions found in most agricultural soils are seldom toxic. On the other hand, much higher concentrations of certain salts and much higher total concentrations are sometimes found, especially in the soils of arid and semiarid sections. This is due in part to lack of rainfall sufficient to leach away surpluses and in part to the effect of long-continued evaporation bringing up dissolved materials from the lower soil levels and depositing them in the surface layers. The salts in these heavily impregnated soils are called *alkali*, and the soils themselves are spoken of as *alkali soils* (not *alkaline soils*). About the only way to correct alkali soils is to flood them with enough irrigation water to dissolve out the surplus salts and carry them away through drainage water or to lower levels where they will not be harmful to crop plants. There are great differences between crop plants in their ability to tolerate alkali. Thus, among fruit crops the grape is relatively tolerant while the peach is not; among vegetables the beet is far more tolerant than is the tomato. Among ornamentals the cocoanut palm (*Cocos nucifera*), Australian pine (*Casuarina equisetifolia*), Spanish dagger (*Yucca aloifolia*), sea grape (*Coccoloba uvifera*), and skeleton plant (*Euphorbia candelabra*) will grow where some of their roots are bathed with the salt water of the ocean at high tide, and their leaves are frequently covered with salt-water spray — conditions under which the orange, hibiscus, and croton would promptly die. Probably more practicable than trying to reduce the salt content of alkali soils is the selection of plants that will thrive in or at least tolerate them.

That it is good practice to supply plants with ample amounts of nutrients for their growth and development is more or less obvious. This does not mean, however, that unlimited surpluses should be provided. In the first place such surpluses entail unnecessary costs, for though some of the surplus amounts may be held in the soil for years until they are finally used, others will be leached out and lost. More important is the fact that unnecessarily heavy applications of fertilizers often result in such high concentrations in the soil solutions that they become toxic to the plants. In some instances the roots are injured; in others the materials are taken up without apparent injury to the roots, only to be deposited in the leaves in quantities sufficient to cause "burning" (see Figure 74). In either case more harm is done than benefit derived. A similar situation is often met when nutrients are applied in the rows — of hill or row crops — in the amounts entirely appropriate for even or broadcast distribution over the entire area. It is often found desirable to make split applications in order to avoid toxic effects from the too great concentrations of readily soluble fertilizers. This makes possible the maximum benefit from placing fertilizer close to the young plants where they can readily get it. This may mean broadcasting part of it over the entire area and distributing the remainder in or along the rows, or the entire amount may be placed along the rows, but two or three partial applications are made at three- to six-week intervals.

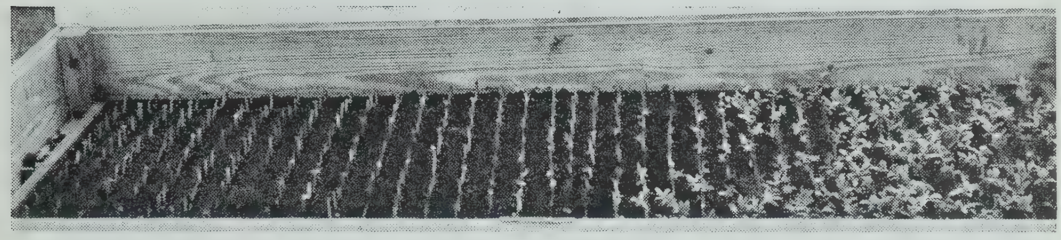

FIG. 74. A propagating frame of blueberry cuttings. Thinking to hasten rooting and promote a more rapid growth, the propagator gave the left two-thirds of the frame an application of commercial fertilizer; the portion of the frame on the right was left untreated. The fertilizer proved toxic to the cuttings.

Because light, coarse-textured soils hold less capillary or available water than those of fine texture, application of a given amount of readily soluble fertilizer to a given area results in a higher concentration of the material in the soil solution, and the danger from "burning" is correspondingly greater. Consequently, more care needs to be employed in the fertilizing of light soils than in remedying heavier soils; this is unfortunate because usually the lighter soils need the heavier applications. Danger of injury from high concentrations of nutrient materials is likewise great in potted plants and in greenhouse benches and beds where there is only a limited amount of soil per plant.

SOIL REACTION

The chemist classifies most of the more common elements that make up the body of our soils either as basic or acid. By this is meant that when, say, sulphur or carbon or nitrogen or phosphorus is oxidized (burned), the resulting oxide combines readily with water, and the resulting product is acid. When elements of the other group (for example, calcium, magnesium, potassium) are similarly oxidized, they too combine with water; the resulting products possess chemical properties more or less the opposite of those of the acid group. The acid products and basic products combine or interact readily to form neutral salts that are neither basic nor acid in reaction. In a soil where the basic elements predominate — or more accurately, that portion of the basic elements which goes into solution in water predominates — the resulting mass reaction will be basic; where the acid elements that are in solution are quantitatively greater than the basic, the resulting mass reaction is acid; where the two groups are in approximate equilibrium, the soil is neutral.

Few agricultural soils are exactly neutral, most being either slightly basic or more or less acid. Furthermore, a soil that is exactly neutral at one time does not remain so indefinitely. With a change in the relative amounts of basic or acid elements in solution — a change that may be brought about by leaching or absorption by growing plants or any one of several other factors — it may become either acid or basic, or if it is either acid or basic to start with, it may subsequently become either more or less acid or more or less basic, or it may change from basic to acid or from acid to basic. The disintegration of crop residues in the soil through the action of bacteria may result in the formation of certain organic acids that likewise tend to acidify the soil. Some soils, those whose main constituent materials (that is, the rock from which the soils were originally derived) are basic, tend naturally to be basic, or at least neutral, in reaction. Included here are most granitic and limestone soils, though eventually some of these become neutral or acid as a result of leaching. Others, as for instance those that are derived mainly from silica, tend to be acid in reaction. On the whole, basic materials more readily dissolve out and are carried away in the drainage water than the acid-forming materials. Therefore, neutral and basic soils are most frequently found in arid or semiarid and in the plains regions; acid soils are more typical of areas of heavy rainfall.

As indicated in the preceding paragraph the basic and acidic elements are basic or acidic *in effect* only in combination with water. Indeed, a more modern concept of the situation than the one just presented is that what makes the soil solution acid or basic are the hydrogen (H) and hydroxyl (OH) ions that result from a splitting of the water into its two components. The hydrogen ions carry a positive electrical charge which gives them their acid qualities, and the hydroxyl ions carry a negative charge which gives them their basic qualities. The so-called *basic* and *acid* elements or materials such as sodium and sulphur simply are effective in breaking down or ionizing the water and then in uniting with or tying up one of the ions, leaving the other free to make the solution basic or acid as the case may be. According to this concept the degree of acidity or alkalinity (basicity) of any solution may be expressed in terms of the concentration of its hydrogen (H) or hydroxyl (OH) ions. It has been found that in pure water, which is neutral, each liter (1,000 grams) contains approximately .0000001 gram of hydrogen and likewise .0000001 gram of OH (hydroxyl) in an ionic form — that is, uncombined and carrying positive and negative electrical charges, respectively. Now 7 is the logarithm of the reciprocal of .0000001 and is therefore arbitrarily taken to express the hydrogen ion concentration and also the hydroxyl ion concentration in a *neutral* solution. If a certain solution has 10 times as many free hydrogen ions per liter we say that it has a hydrogen ion concentration of 6 — expressed as pH_6 and mean that 6 is the logarithm of the reciprocal of the percentage of free hydrogen ions that it contains. Similarly, a pH of 5 or of 4 means that the solution is 10 times or 100 times, respectively, as acid as the one with a pH of 6 or 100 times and 1,000 times, respectively, as acid as the one with the pH of 7. Theoretically, hydrogen ion concentrations may run as high as pH = 0, and hydroxyl ion concentrations as great as pH = 14. In reality the pH range of agricultural soils ranges between pH_3 and pH_9 and the most fertile soils between pH_5 and pH_8.

Soil reaction is important in a number of ways in influencing plant growth. In the first place, plants vary greatly in their reactions to soil acidity, just as they vary in their response to drought or fertility or temperature. Some (as most of the clovers and other legumes) grow best in a soil that is slightly basic, neutral or only slightly acid in reaction; others, such as the strawberry, cabbage, orange, and raspberry, grow best in a soil that is mildly acid; still others, as the blueberry, azalea, and rhododendron, grow best in soils that are sharply acid and die in those that are neutral or only slightly acid. Some of these differences in plant response to soil reactions are illustrated in Figures 75 and 76. Little can be offered in the way of explanation of why plants show these different responses to soil reaction, except that in the course of time those inhabiting regions where the soils are neutral or basic have gradually become adjusted to such a condition while those inhabiting regions where the soil is acid have evolved in a different direction.

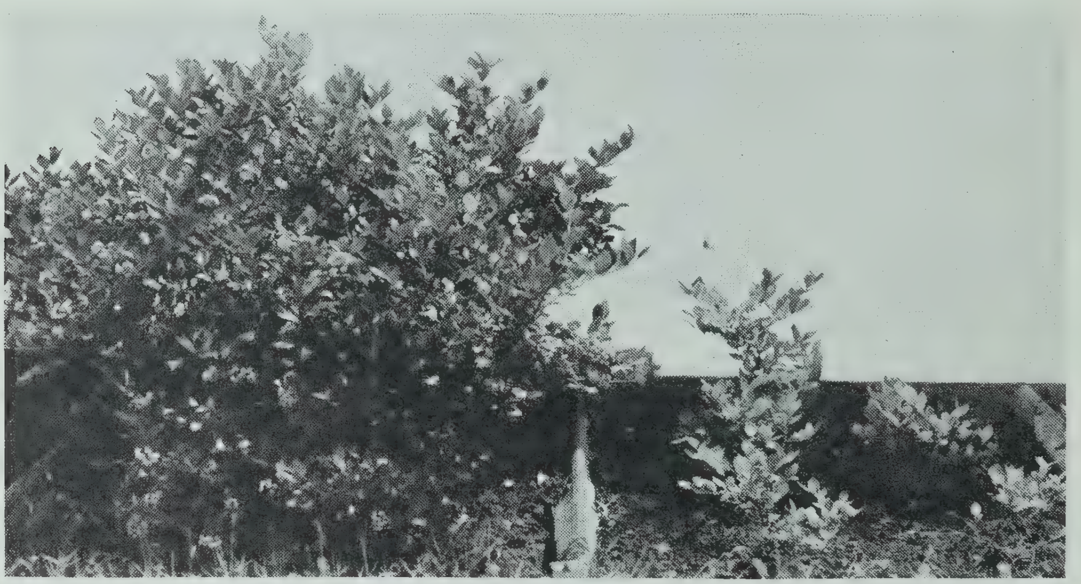

FIG. 75. On the left are high-bush blueberry plants growing in a very acid sandy loam (pH 4.7). On the right are plants of the same variety and age growing in a fertile garden loam that has a neutral or very slightly acid reaction. Compare with the potatoes shown in Figure 76.

Soil reaction in itself directly influences both the rate of solubility and the availability of certain plant nutrients. Thus, iron-containing compounds are very insoluble and relatively unavailable to plants in a neutral or basic medium, while they are much more readily available in an acid medium.

Certain kinds or groups of soil-inhabiting bacteria are active only when the soil is approximately neutral; others are active at moderate acidity. Consequently, the biochemical changes going on within the soil, especially those involved in the decomposition of plant residues, are greatly influenced by soil reaction. One of the more important ways in which certain fertilizer applications influence plants is through their effect on bacterial activity.

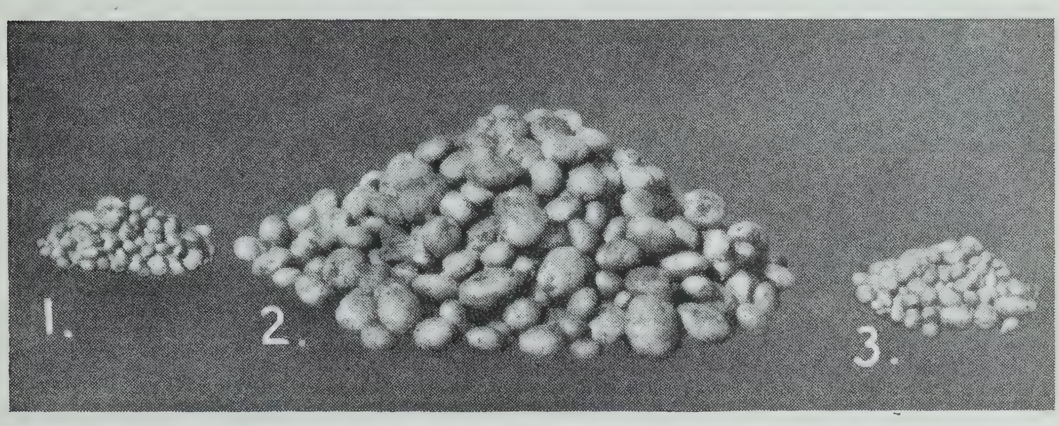

Fig. 76. The three piles of potatoes represent the crops from the same number of hills grown in a very acid (pH 4.4 before treatment) muck soil. The pile at the left was from a plot to which phosphorus and potash were applied, but nothing was done to change its reaction. The pile on the right was from a plot to which lime was added to neutralize partially its acidity, but no phosphorus or potash was applied. The pile in the center received lime, phosphorus, and potash. Compare with Figure 75.

In general, the easiest and least expensive thing for the farmer to do is to take soil reactions as he finds them and choose plants to grow on a particular soil that naturally thrive in that particular condition. If his soil is approximately neutral, he has a wide range of crop plants that will grow well in it; if it is sharply acid or alkaline, he should limit his planting to acid-tolerant or alkali-tolerant crops, unless he is prepared to go to the expense of changing soil reaction. In those cases, however, where relatively small changes in the reaction are necessary in order to meet the requirements of certain crop plants, treatment may be entirely practicable. Thus, the liming of soils to reduce their acidity has become a regular practice on many farms, especially for such crops as alfalfa, clover, and beans. Acidifying the soil with sulphur or by incorporating with it some highly acid peat, is a common practice in the culture of many ornamentals, such as rhododendrons and azaleas.

The water obtained from wells often contains considerable quantities of basic materials, and its continued use in watering greenhouse-grown plants results rather quickly in markedly changing the soil reaction in greenhouse beds, benches, and pots. In a number of places it has become standard practice to "condition" this water by treating it with phosphoric acid, thereby maintaining neutrality or a slightly acid condition. In many sections potato-growers hesitate to lime their land for alfalfa which may be grown in rotation with the potato crop, even though it is needed for the alfalfa, because the scab organism which works on the tubers grows much better in a neutral soil than in an acid soil. Acid peat is especially valuable as a medium for the rooting of cuttings of certain plants such as the blueberry (*Vaccinium corymbosum*) because it is so highly acid ($pH_{3.4}$ to $pH_{4.5}$). This is partly because the blueberry plant itself prefers a sharply acid medium in which to grow and partly because the high acidity of the peat discourages the growth of fungi and other organisms that often infect and destroy cuttings placed in other media. The soil-reaction preferences and tolerances of many crop plants, particularly ornamentals, are as yet none too well established. There is reason to believe that much can be accomplished in their culture by giving greater attention to their peculiarities in this respect.

In the absence of definite information on reaction obtained through the use of standard tests, a fairly dependable estimate can be made by noting the kinds of plants growing wild and thriving in areas that have not been brought under cultivation. For instance, clovers and most other legumes thrive best only on neutral, slightly alkaline, or at most only very slightly acid soils; beech and maple trees similarly prefer a neutral or nearly neutral soil; oaks grow better where it is mildly acid; wild blackberries, dewberries, and strawberries grow best where the soil is moderately acid; cranberries, blueberries, and rhododendrons grow well only where it is sharply acid. By carefully noting the kinds of plants growing wild and thriving on a soil of unknown reaction, it is usually possible to tell the kinds of crop plants that may be grown on it successfully.

So important is the influence of soil reaction on the growth and behavior of plants that every plant-grower should know not only the approximate soil reaction of his different soil types but the degrees of acidity or alkalinity both tolerated and preferred by the different crops he is raising. For this purpose he can use any one of several of the quick color reaction-testing outfits, such as the Spurway "Soiltex" or the La Motte. Furthermore, such tests should be repeated periodically, as reaction changes gradually because of leaching, fertilizer applications, irrigation, cropping systems, and other factors. Frequent tests should be made of greenhouse soils so that proper corrective measures can be employed, where necessary, as such soils are subject to rapid changes in reaction, caused especially by watering with "hard" water.

PROBLEMS

1. What is the distinction between *solubility* and *availability* as these terms are applied to plant nutrients?

2. What is the distinction between *alkali* and *alkalinity* as these terms are applied to soil conditions?

3. Is availability of a certain nutrient material a function of the soil? Of the plant? Or of both? Explain.

4. How, if at all, does nutrient absorption by the plant differ from the purely physical process of diffusion?

5. If the concentration of nutrient substances in solution in the soil must be higher than that of the same substances within the plant root, how do you account for absorption continuing after the withdrawal of a portion of the soil solutes?

6. Sometimes plants "bleed" when they are bruised or cut; sometimes they do not. How do you account for this?

7. In general would you expect soils in regions where there is considerable trouble from alkali to be more or less alkaline than those in regions where there is seldom or never trouble from alkali? Why?

8. Would you expect plants to be more likely to be "burned" from heavy fertilizer applications on sandy or on clay soils? Why?

9. Which would you expect to parallel most closely the daily and seasonal variations in the evaporating power of the air — nutrient absorption or water absorption? Why?

10. Which would you expect to parallel most closely the seasonal variations in rate of new growth — nutrient absorption or water absorption? Why?

11. Is it necessary or highly desirable that in applying fertilizers to soils for different crops their composition be varied so that the several nutrient elements are present in approximately the same proportions that the plant absorbs them? Or is this unimportant? Explain.

CHAPTER X

CARBOHYDRATES

MOST plant tissues contain from something less than 5 to more than 90 per cent dry matter, water making up the remainder of their weight; carbohydrates of one kind or another usually constitute from 50 to 90 per cent of their dry matter. Thus, from 6 to 7 of the 7 to 8 pounds of dry matter in a bushel of apples is carbohydrate; 10 of the 12 pounds in a bushel of potatoes; 1,300 of the 1,825 pounds of dry matter in a ton of alfalfa hay; 90 of the 150 pounds of dry matter in a ton of cabbage; and 2,900 to 2,950 of the 3,000 pounds of dry matter in a cord of wood. Furthermore, carbohydrates furnish the main bulk of the material that goes into the make-up of the other organic substances of the plant, including the proteins, oils, acids, alkaloids, pigments, etc. Carbohydrates bear much the same relation to the plant when it is considered substantively as do its cells when it is considered from the standpoint of structure. Figuratively, they are the building blocks out of which the plant is constructed.

It is thus evident that, since carbohydrates are basic materials in the plant's structure and economy, plant growth and development must center around carbohydrate manufacture and utilization.

A carbohydrate is a substance consisting of carbon, hydrogen, and oxygen in which there are twice as many hydrogen as oxygen atoms and either as many or one more carbon atoms as there are of oxygen. They thus have the general chemical formula:

x or $x + 1$ number of carbon atoms, $2\,x$ number
of hydrogen atoms, and x number of oxygen atoms

There are other classes of compounds, such as some of the fats, which likewise are composed of carbon, hydrogen, and oxygen, but these elements are present in different proportions than in carbohydrates. There are many naturally occurring carbohydrates in plants, such as grape sugar, cane sugar, starch, pectin, and inulin. Cellulose, which comprises the walls of relatively young plant cells, is a carbohydrate, differing from the ones just mentioned in being relatively insoluble in water and not so readily transformed into other carbohydrates by enzymatic or other agencies. Woody tissues consist mainly of mixtures of several, closely related, complex carbohydrates that likewise are not soluble and that likewise are comparatively resistant to the action of other agencies. These cellulosic carbohydrates are often spoken of as crude fiber, though, strictly, the fibrous and woody tissues of both bark and wood usually include limited quantities of gums, resins, and mineral substances.

Apparently the simple sugars, such as grape sugar, are the first-formed carbohydrates in plants, and these are readily soluble and can be easily translocated from one place to another. Movement of soluble carbohydrates and other foods from one cell to an adjoining one is brought about by osmosis; their translocation from one part of the plant to a distant part takes place mostly through the vascular inside layer (phloem) of the bark. In certain parts of some plants — for example, the roots of beets, the stems of sugar cane, and in many fruits — sugars may accumulate in considerable amounts. In other plants or in other places sugars do not accumulate but are promptly changed over into starch (as in the potato tuber or in the seed of the rice plant) or inulin (as in the onion bulb and dahlia root) or hemicellulose (as in the seed of the date palm). In still others, as in the trunks of trees and the bony coverings of seeds and nuts, they are rather promptly transformed into cellulose, lignin, and related substances. When present in the form of sugar, starch, inulin, pectin, dextrin, etc., they are readily hydrolyzable or digestible and can be used for various purposes; when once built up and deposited in the form of cellulose or lignin, they are not changed back into the simple forms, but become locked up in the permanent structure or framework of the plant. Many of these chemical changes from one carbohydrate to another can be produced in the laboratory under proper conditions and with the aid of certain enzymes. In the plant they take place in an orderly fashion and are just as characteristic of certain plants or certain of their organs and tissues as are the forms of their leaves, the color of their flowers, and season of maturity of their fruits. Like these structural characteristics, they are governed by hereditary factors. On the other hand, they are influenced to some extent by both internal and external conditions and therefore are under control to a limited degree. Thus, relatively high temperature and a limited water supply accelerate lignification in many tissues, such as the pods of the string bean, the leaf stalks of celery, and the roots of the radish; low temperature while sweet corn is in the "milk" stage retards the change of sugar into starch and thus promotes better quality; frost, just as the fruit is ripening, breaks down the tannin of persimmon fruits and makes them "sweet."

CARBOHYDRATE MANUFACTURE

In the chapter on "Light as a Limiting Factor," the photosynthetic process has been explained in sufficient detail for this text, and it was stated that carbohydrate is its end product. In view of the fact that carbohydrates alone form such a large portion of the substance of all plants and are essential ingredients in the synthesis of most of their other constituents, photosynthesis can be considered as the most important of all plant processes. Indeed, much of man's effort in his culture of plants is directed toward seeing that conditions are provided which do not become limiting factors to carbohydrate manufacture. It is mainly for this reason that he plows, cultivates, and mulches the soil, thereby providing for an adequate water supply, which, in turn, is a means of obtaining carbon dioxide. He prunes, stakes, trains, and trellises his plants so as to afford a larger percentage of their leaf surface a better and a more uniform supply of light. He sprays so as to protect leaves from insect and disease attack and thus prevent a reduction in their photosynthetic capacity. Even a part of his fertilizer applications are for the purpose of aiding carbohydrate manufacture through increasing the numbers and sizes of leaves and the amount of their green coloring matter.

CARBOHYDRATE UTILIZATION

In any form carbohydrates are to be regarded as latent or stored energy. We release the energy stored in cellulose instantaneously and violently when gun cotton (nitrated cellulose) is exploded. The latent energy of lignin and related carbohydrates is released rapidly in the form of heat when we burn wood or dried peat or plant residues of any kind; that of starch and sugar is liberated slowly in the animal organism when it is consumed (burned) to maintain body temperature or to perform work. The end products that are obtained incident to the release of this energy are carbon dioxide and water, the ingredients that went into the carbohydrates when they were synthesized. The whole process of carbohydrate utilization, by a living organism, with its release of energy and the liberation of carbon dioxide and water is *respiration*. The world over photosynthesis is the principal means by which the energy of sunlight can be trapped, and carbohydrates are the principal form in which it is held in storage for future use.

From the standpoint of the animal we think of carbohydrates as a source of energy; from the standpoint of the plant we think of them as storage products or as going into the more or less permanent framework and structure of the plant. The difference in their utilization by the plant and animal, however, is one of degree rather than kind, for both plants and animals use carbohydrates as a source of energy, and in both carbohydrates are found as important constituents of their body tissues. Animals use relatively more of their carbohydrates as a *source of energy* and plants use relatively more for *tissue-building* — that is all. Few realize the percentages of the total supply of carbohydrates synthesized by plants that are promptly used as a source of energy for their growth processes. The energy required for combining carbon dioxide and water to form carbohydrates in the green parts of the plant is derived directly from sunlight, but that which is required somewhere else in the plant for synthesizing proteins, oils, alkaloids, pigments, and other products from the food materials and nutrients out of which they are made must be derived from the breaking down of carbohydrates, just as in the animal organism. It has been estimated that under average conditions from three fourths to four fifths of the total carbohydrate manufactured by the plant is thus broken down and utilized by it to support respiration and other plant functions, leaving only a fifth to a fourth that may be used for storage or building into its permanent framework. In this connection attention is called to the fact that the living plant is respiring constantly, night and day, while photosynthesis takes place only during the presence of light. The rate of respiration is influenced by temperature, just as is photosynthesis, but it is less subject to the influence of light and water supply. The ripening and after-ripening processes and later deterioration of plants or plant parts, such as fruits, bulbs, tubers, etc., after harvest is in considerable part a matter of respiration, though other chemical and physical changes are involved. They can all be retarded by storage at low temperatures (32° to 40° F.). When grown at too high temperatures, many plants respire more rapidly than they are able to manufacture carbohydrates, the result being failure to develop satisfactorily or even deterioration. High respiration rate shortens the length of time seeds retain their vitality and sets the southern limit to the practical culture of many plants.

CARBOHYDRATE SURPLUSES AND DEFICIENCIES

When an animal does not have a supply of carbohydrates sufficient for its normal respiration requirements, it loses weight, becomes emaciated, and finally most of its life processes acquire a slow pace. When it gets more carbohydrates than are required for normal activity, it gains in weight, perhaps in part through new growth, or perhaps without new tissue formation. In the latter case some of the surplus may be stored as carbohydrates, though more is changed to fat and stored in that form. Similarly, in a plant when carbohydrate manufacture does not keep pace with respiration, there is a slowing down in growth rate, followed by complete cessation of growth and then by some decrease in dry weight. When the rate of carbohydrate manufacture exceeds its utilization, the plant either grows, or its tissues accumulate them in one form or another.

Carbohydrate-deficient leaves usually possess normal green color and appearance, though they are likely to be rather soft in texture and low in percentage of dry weight. The same is true of carbohydrate-deficient stems, except, of course, in the matter of color of older stems in which the green has largely disappeared. On the other hand, leaves in which relatively large quantities of carbohydrates have accumulated acquire a yellowish-green, and in some instances a dull purplish cast, and resemble those exhibiting nitrogen-deficiency symptoms. As a matter of fact, nitrogen deficiencies and carbohydrate surpluses are very likely to be found together, and yellowish-green foliage is a symptom of the resulting condition rather than of first nitrogen deficiency or carbohydrate surplus.

Woody tissues that are well stocked with hydrolyzable carbohydrates have a relatively high percentage of dry matter and are less subject to injury from severe cold or drought than those less well supplied. The hardening process in herbaceous plants and the maturing of woody tissues in the fall are in considerable measure due to the accumulation of carbohydrates. The maturing of many fruits and vegetables, or at least the development of what we call *high quality* in them as they acquire maturity is usually associated with the storage of surplus carbohydrates — often certain specific carbohydrates, as sugar. Specimens low in this group of materials are unduly acid, insipid, or otherwise off flavor, and often are poorly colored. High quality in most fruits and in many vegetables is associated with relatively large amounts of the carbohydrates characteristic of the product in question. Carbohydrates are employed in the synthesis of anthocyanin and other pigments which give fruits their characteristic color and develop freely only when surpluses over and above those required for other growth processes are available. It is for this reason that both high color and high quality of apples are associated with a combination of bright sunny days and cool nights preceding the ripening season. At this time carbohydrate manufacture is proceeding at a high rate, and if nights are cool, respiration is comparatively slow, thus permitting rapid carbohydrate accumulation. If the nights are warm, respiration proceeds at a faster pace; carbohydrate accumulation is less rapid; and quality and color do not reach such high levels. Heavy carbohydrate utilization in the formation of flowers on orange trees occasions a temporary deterioration in the quality of their mature but unharvested fruits; quality, however, is restored following blossoming as the leaves have a chance to replenish the supply of carbohydrates.

CONTROL OF CARBOHYDRATES

Carbohydrate content of any plant as a whole at any particular time is equivalent to the difference between what has been manufactured up to that time and what has been used in respiration, for new tissue formation, and in the synthesis of other compounds, such as fats and proteins. Carbohydrate content of any particular plant organ or tissue at any particular time similarly depends on what has been manufactured and what has been utilized, but it likewise depends on what may have been translocated to or away from that particular organ or tissue. Carbohydrate manufacture, as has been stated, is limited to those organs (leaves and, in some cases, stems) and tissues containing chlorophyll. From them it is translocated to all parts of the plant, and utilization occurs in all parts of the plant. Man can exercise only indirect control over carbohydrate manufacture through such practices as shading, irrigation, cultivation, spraying, and pruning. His control over carbohydrate utilization is likewise indirect and perhaps even less complete. However, through such control of temperature as he may have in some cases and, as will be explained in some detail in the next chapter, through altering the available supply of certain nutrients, and to a lesser extent by certain other practices, he can accelerate or retard the rate of carbohydrate utilization both for respiration and for new tissue formation. Thus, through both of these indirect methods he may exercise some control over carbohydrate content of the plant as a whole at any particular time.

A somewhat greater degree of control of the carbohydrate content of plant organs and tissues may be obtained by means of certain rather special practices and treatments, that tend to accelerate or interfere with the normal translocation of carbohydrates. As has been mentioned, they travel from one place to another mainly through the inner bark layer (phloem). Notching, girdling, tightly binding, twisting, or even bruising the bark of the trunk or limbs of trees, shrubs, or vines will prevent or retard the movement of carbohydrates from leaves to roots and to those parts of the stem below the points of injury. This leads to their accumulation above the point of girdling or other injury. This, in turn, as will be seen in the next chapter, may greatly influence such plant functions as flowering and fruit-setting, size and quality of flowers and fruit, and amount of new vegetative growth. The bending of canes, shoots, and vines incident to staking and trellising similarly influences the translocation of carbohydrates from top to root and from branch to branch in the top. Partial crushing and breaking of herbaceous stems from wind (as in the lodging of grain) or intentionally through the use of a roller, effects similar changes in normal carbohydrate translocation and in the composition of affected organs and tissues. The dwarfing and other effects of certain fruit and ornamental stocks is brought about, at least in part, through the influence of the graft unions on carbohydrate translocation.

There is no general rule for determining whether the *normal* distribution of carbohydrates between different parts of the plant or some abnormal, artificial distribution best serves the purposes for which the plant is being grown. If an apple, kumquat, or any other tree is being grown in the orchard for the purpose of producing as much fruit as possible, a more or less *normal* distribution of carbohydrates between top and root will doubtless produce the largest tree and most fruit; if small *specimen* plants are wanted primarily for ornament in the kitchen garden or greenhouse, a somewhat different distribution is more likely to produce the type of growth desired. Elephant's-ear (*Colocasia esculenta*), cultivated in tropical countries for its edible, starchy roots, should be so grown that there is maximum carbohydrate storage in its roots; the related types grown in the greenhouses of temperate climates for their attractive foliage, *Caladium bicolor* and *C. picturatum*, should be so handled that there is a minimum of carbohydrate storage and a maximum utilization for leaf production. Peas and sweet corn harvested one day will have a maximum sugar content and be at their best; harvested a day or two later their sugar content will be lower, their starch content higher, and they will have appreciably deteriorated in quality. In contrast cantaloupes and grapes harvested one day may have little sugar and much starch and be practically inedible; harvested two or three days later, they may have more sugar and less starch and be greatly improved in quality. In both cases the changes in carbohydrate content are due in part to changes in the proportions of the several kinds already present in the fruits or seeds and in part to translocation from other parts of the plant. With a knowledge of the changes in carbohydrate content which normally occur and a knowledge of how such changes may be influenced locally within the plant, the grower is often able to influence substantially the size, composition, and quality of his crop.

PROBLEMS

1. What are the raw materials or ingredients from which carbohydrates are made?
2. From what does the plant derive the energy for carbohydrate manufacture?
3. Where are carbohydrates manufactured? Where stored? Where utilized?
4. What is respiration?
5. In the process of respiration is energy utilized or released? Explain.

6. Present evidence that plants sometimes manufacture carbohydrates more rapidly than they utilize them.

7. Present evidence that plants sometimes use carbohydrates more rapidly than they manufacture them?

8. Why is grape juice or wine made from grapes some seasons better in quality than that made other seasons? Explain fully.

9. What relation, if any, does respiration bear to carbohydrates?

10. What relation, if any, does respiration bear to transpiration?

11. Would you expect a peach tree to manufacture the most carbohydrate during an average week in May or in July or in September? Why? During which of the three weeks would you expect the greatest net accumulation of carbohydrates? Why?

12. Do carbohydrates as such make up more nearly 5 to 10 or 50 to 60 or 80 to 90 per cent of the dry weight of: (1) woody tissue, (2) the tissues of the fruit, (3) the leafy tissues of vegetables? Explain what part, if any, carbohydrates play in the make-up of the remaining percentages of wood, fruit, and leaves.

13. Explain why cantaloupes fail to ripen properly after the leaves have been more or less seriously injured by leaf spot or some other leaf-destroying disease.

CHAPTER XI

GROWTH AND FRUITFULNESS

MOST plants go through two periods in completing their life cycle. The first is a period of growth in which they attain a certain stature, in part determined by the nature or kind of plant and in part conditioned by environment, and in which they develop only strictly vegetative structures (roots, stems, leaves, rootstocks, bulbs, etc.). The second is a period during which perhaps little more vegetative growth is made, or if they continue to increase in size, the increase is relatively slower, while flower buds, flowers, fruits, and seeds are formed.

In annuals both periods are necessarily short. The first may last for only a few weeks, as in the radish, cucumber, and pansy, or it may continue for several months, as in tobacco and the garden aster; this is followed by a shorter period for flowering and seed production. In biennials, such as the beet and parsnip, vegetative growth only is produced during the first year; flowering and seed production take place the second year; then the plant dies.

In perennials there may be one or several or many seasons of purely vegetative growth before the plant develops flower buds, flowers, fruits, and seeds. In the century plant (*Agave americana*) the purely vegetative period may last for several decades, or even a century, to be followed by a blossoming and seed-forming period of only a few weeks, and then death. In the great majority of perennials, however, there is a series of vegetative periods, each followed by a flowering and fruiting period. Thus, the asparagus plant simply grows without flowering for two or three seasons, until it attains a certain size and accumulates a sizable reserve of foods in its roots and crowns; in its third or fourth growing season it produces flowers and seed; each year thereafter it first makes vegetative growth in spring and early summer, followed by flowers and seeds in late summer and fall. Its above-ground growth is like that of an annual but its crowns and roots live indefinitely.

Raspberries, blackberries, and most of the other so-called *bramble* fruits are perennial plants with biennial canes. Vigorous, vegetative *shoots* are produced one season. The next season these one-year-old *canes* — a shoot automatically becomes a cane when one year old — throw out short flowering and fruiting laterals, and after the fruits and seeds mature, the whole cane dies to the ground. In the meantime, however, while the canes are fruiting, new vegetative shoots are being produced from the crowns so that during any one growing season the tops of the plants consist of young vegetative shoots and older reproductive canes, all growing from perennial roots and crowns.

In woody perennials (trees, shrubs, and vines) there is usually a period of two or three to perhaps ten or twenty years in which the only growth is vegetative; then the plant acquires a fruitful condition and perhaps every year makes some new vegetative growth and also flowers and produces seed. These two processes or functions are often carried on during different parts of the growing season rather than concurrently. Furthermore, in many of these woody plants growing under natural conditions where competition and the struggle for existence is severe, flowering and fruiting come at irregular intervals of two, three, or four years rather than every year, with intervening periods of vegetative growth only. Thus, whether the plant is an annual, biennial, or perennial, it is characterized by more or less alternation of vegetative growth and reproductive activity. When in cultivated plants this alternation results in periods of a year or longer in which no flowers and fruits are formed, we have *alternate* bearing.

EXTERNAL AND INTERNAL CONDITIONS FAVORING VEGETATIVE GROWTH

Long experience on the part of cultivators has taught them that certain conditions favor the vegetative development of plants. Sometimes when these conditions are particularly favorable, reproduction is considerably delayed or even prevented. In general these conditions include an abundant water supply, optimum or above optimum temperatures, and optimum or below optimum light intensities for the growth of the plant in question and an abundant supply of nutrients, especially nitrogen, in a readily available form.

Grain and hay crops under the conditions just described make a rank succulent growth that is subject to lodging. They are somewhat later than usual in reaching the harvesting stage, and their seed crop is very likely to be light. The farmer complains that the grain doesn't "fill." Under similar conditions tomato, cucumber, melon, and many other annual plants "run to vine." They may form some flowers, but few fruits "set" and mature, and these ripen later than usual. Potato and onion plants likewise "run to vine" in very rich soils, though with them delayed and reduced tuber and bulb rather than fruit formation are associated with the rank top growth. In the case of strawberries, running to vine means surplus or excessive runner formation. Fruit trees, shrubs, and vines grow to large size, do not come into bearing until perhaps twice or three times their usual bearing age, and then yield sparingly. Seldom, with any of these plants, are flowering, fruit, and seed production entirely inhibited by the overvigorous and overabundant vegetative growth, but they are delayed and reduced in amount. It appears that the vegetative organs and tissues are developed more or less *at the expense* of the reproductive organs and tissues.

The conditions that thus so successfully and uniformly promote vegetative growth at the expense of the reproductive functions will be recognized as conditions favorable for both carbohydrate manufacture and carbohydrate utilization — especially, utilization. Cell division, increase in size of cells with the consequent increase in bulk and the respiration occasioned by greater cell activity are accelerated. The net result is that the plant grows rapidly and is likely to continue growing rapidly *unless or until something intervenes to check it.*

Paradoxical as it may seem, the opposite conditions of environment — poor soil, low light intensity, deficient nutrient supply (especially of nitrogen), and drought which permit only a very slow and limited growth — similarly promote vegetative growth and delay or prevent the initiation and development of the reproductive processes. Perhaps it would be more accurate to say that instead of promoting vegetative growth, these conditions simply don't *prevent* it, while they do prevent or at least *delay* reproduction, for such vegetative growth as takes place is very slow in rate and limited in amount. It is, nevertheless, vegetative growth. Illustrations of unfavorable conditions permitting or allowing a meager vegetative growth where at the same time they indefinitely delay or entirely prevent flowering and fruit and seed formation are perhaps more numerous than those in which extremely favorable conditions actually *promote* the one at the expense of the other. Such is the case when forest-tree reproduction is taking place, and the stand of young forest-tree seedlings, such as is shown in Figure 77, is many times the number that space will permit to grow to maturity. Here it is soil moisture and nutrients and particularly light that are the limiting factors. Trees of species that in the open would reach a size where flowering and seed production would take place in ten to twenty years will struggle along for half a century or more without any sign or possibility of producing seeds, and a large percentage will finally die before flowering. Unfavorable conditions are found in nearly every untilled spot in the garden when weeds crowd out each other along with the seeded or planted crop, perhaps less than 10 per cent surviving until they are able to produce flowers. Here, as in the forest, deficiencies of light, moisture, and nutrients are the limiting factors. In the grain field or meadow, where either intentionally or accidentally more seed was sown in a given area than can possibly survive, many individual plants fail to flower and produce seed. In the desert limited moisture supply permits only a small portion of the natural stand of seedlings to survive. On the barren rocky mountainside the scanty soil lodged in crevices is sufficient for the support of only a few plants. In many more or less neglected orchards planted on poor soils the trees may survive for many decades, but because of starvation and the attacks of insects and disease few or no fruits are produced.

Though the environmental conditions that are associated with and responsible for a slow, weak, dwarf type of vegetative growth are just the opposite of those that cause plants to run to vine, they tend to bring about a more or less comparable nutritive condition within the plant, at least insofar as carbohydrate reserves are concerned, though on a lower level. The overvigorous plants under conditions especially favorable for vegetative growth are relatively low in carbohydrate content because the large amounts that they are manufacturing are promptly being utilized; the starved, stunted plants under the opposite conditions are likewise relatively low in carbohydrate content because partial shade or limited water or nutrient supply interfere with the manufacture of carbohydrates. One group of plants may be compared to the

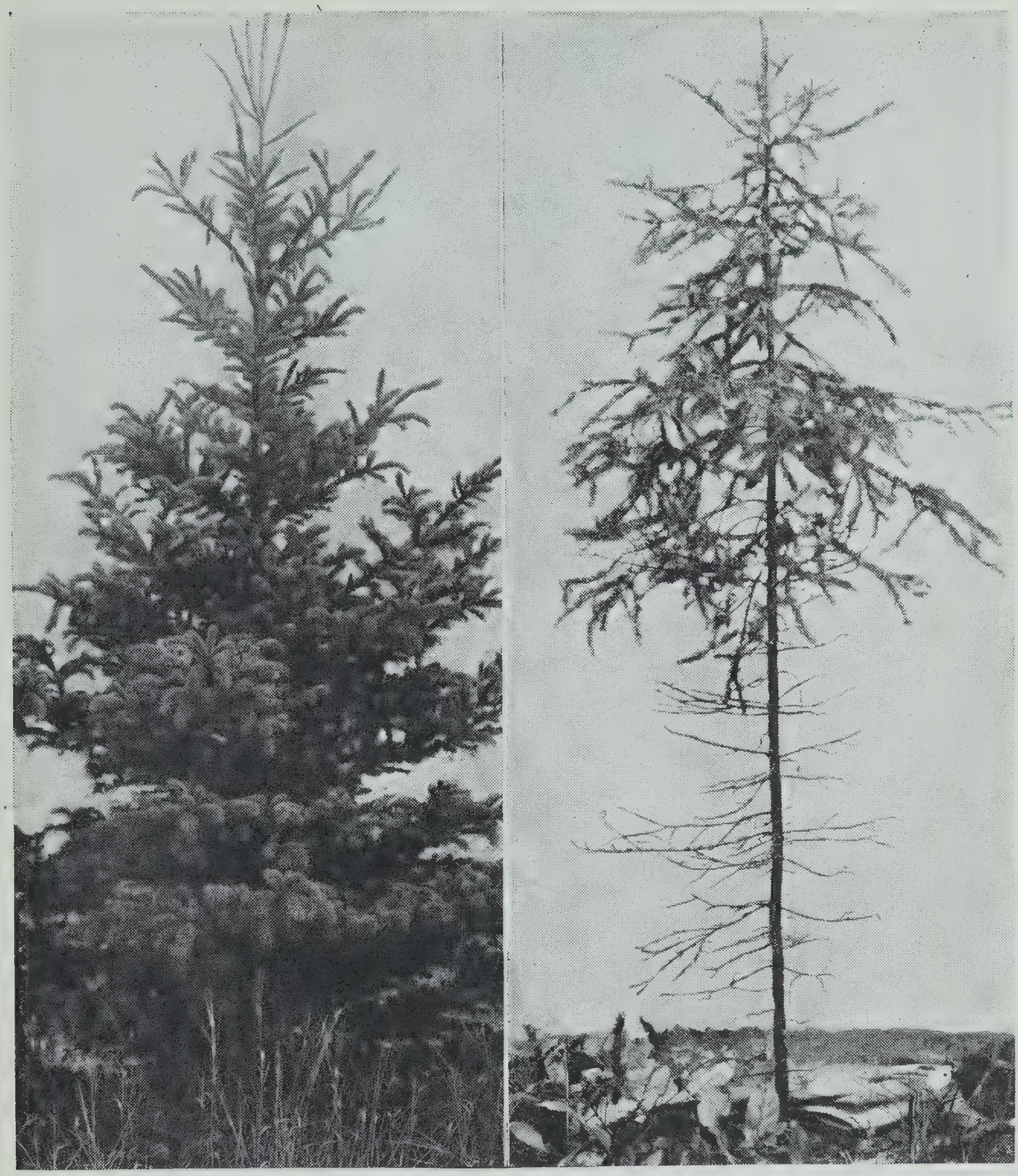

FIG. 77. On the left, a fourteen-year-old tree of the white spruce (*Picea canadensis*) that has developed in the open. Note its wide spread, its live lower branches, its vigour, and the number of cones. On the right, a twenty-year-old tree of the same species, growing on the same soil type, not far from the one pictured on the left, but in a densely crowded stand. Note its general lack of vigour, its dead lower branches, and its lack of cones. Should it survive another twenty years under similar conditions, it would not be likely to reach the reproductive stage.

insolvent individual who has a large income but whose expenditures are always keeping up to or exceeding his receipts; the other group is in the position of the individual who likewise is insolvent, not because he spends much but because his income is practically nil. Both the spendthrift and the hobo may pay their way as they go, but they live on different levels; neither is a "producer."

EXTERNAL AND INTERNAL FACTORS FAVORING REPRODUCTION

Just as there are certain conditions of environment that are especially favorable for vegetative growth, so there are other conditions that seem especially favorable to the development of flower buds, flowers, fruits, and seeds — in other words, of fruitfulness. First and foremost among these are: sufficient room and soil, sufficient water and nutrients, light of sufficient day length and intensity, and a suitable temperature. Moreover, these several limiting factors of environment should be such that a moderately rapid, or normal, but not too rapid, growth may be made. This is but another way of saying that somewhere between the extremes of drought, shade, and starvation, which delay or entirely inhibit reproduction, and the extremes of high fertility and an overabundance of water, room, and sunlight on the other, which bring about an over-vegetative condition, is the mean or average that promotes the reproductive processes. As a matter of fact, within or between the extremes there is a wide range of conditions in which most plants are both moderately vegetative and fruitful. The optimum point or set of conditions from the standpoint of flower, fruit, and seed production for one kind of plant may be somewhat different than that for another.

Characterizing or associated with the more moderate growth that accompanies fruitfulness — as contrasted with the extreme vigor or the extreme weakness of the purely vegetative condition — is an internal condition in which there is more or less of an accumulation, an increase in both the amounts and percentages, of carbohydrates. Indeed, the evidence indicates that the building-up of a surplus of carbohydrates over and above the amount required immediately for respiration and new tissue formation (new vegetative growth) is a necessary antecedent, though not the only necessary antecedent, to the plant's becoming fruitful. This accumulation may be due to more rapid manufacture of carbohydrates or to less rapid utilization, or to both conditions. In the case of the extremely weak vegetative plants carbohydrate accumulation is made possible by more room, light, water, nutrients, a more favorable temperature, or any combination of these and other factors that accelerate their manufacture. In the case of the overvigorous vegetative plants it may be brought about by a reduction in water or nutrient (especially nitrogen) supply, a lowering of temperature, or any combination of these and other factors that retard carbohydrate utilization. Thus, simply thinning the seedlings in the overstocked stand in the forest or destroying the weeds in the garden may be all that is necessary to enable the trees or crop plants that remain to grow normally and accumulate the carbohydrates necessary for flowering, fruit, and seed production. Fertilizing the weakly vegetative orchard tree will enable it to manufacture more carbohydrates; root-pruning the over-vigorous orchard tree may compel it to utilize less carbohydrate through reducing its water and nutrient supply; in both cases carbohydrates accumulate, and the trees become fruitful.

INTERNAL FOOD-AND-NUTRIENT RELATIONSHIPS

If a whole plant or any plant organ or tissue is given to a chemist for analysis, he will report that it contains certain amounts of water, carbohydrate, nitrogen, phosphorus, etc. These may be given in absolute amounts or in percentages of the total, and in turn the amounts of any one constituent may be expressed in terms (that is, percentages) of another. Thus, if a portion of a stem contained 10 grams of carbohydrate, 1 gram of nitrogen, 0.1 gram of phosphorus and 0.01 gram of iron, its carbohydrate-nitrogen proportion or relationship would be 10 to 1 or 10/1; its carbohydrate-iron relationship would be 10/0.01 or 1000/1; its nitrogen-phosphorus relationship would be 1/0.1 or 10/1.

It has just been stated that the accumulation of a surplus of carbohydrates is a necessary antecedent to the plant's becoming fruitful — that is, to its forming flower buds, flowers, fruits, and seeds. At the time such a surplus has been accumulated, it must therefore have a relatively large carbohydrate content, a condition that can be represented graphically by a large letter C. Analyses of plant tissues show that nitrogen content is always smaller than carbohydrate content, so in comparison with the large C nitrogen content can be represented by a small letter N, and the fraction $\mathsf{C}/_{\mathsf{N}}$ will serve to represent graphically their normal carbohydrate-nitrogen relationship. The carbohydrate-phosphorus relationship at the same moment might similarly be represented by the letter $\mathsf{C}/_{\mathsf{P}}$, the nitrogen-phosphorus relationship by the letters N/P, etc. These relationships are important in determining whether the plant is going to use up its supply of carbohydrates in making new vegetative growth or is going to accumulate them in the form of stored surpluses. This is understandable when it is recalled that the carbohydrates and the nitrogen, phosphorus, and other mineral nutrients obtained from the soil are the constituents out of which the new cells and tissues are built. The plant cannot build new tissues out of carbohydrates alone, or nitrogen or phosphorus or any other element alone. Each tissue has a fairly definite chemical pattern or composition (allowing, of course, for some change from season to season and changes in environment), and the ingredients must be supplied in amounts or proportions to make possible the building of that pattern. Thus, for 100 grams of tissue of a certain kind there might be 80 grams of water, 19 grams of carbohydrate, 0.3 gram of nitrogen, 0.1 gram of calcium, 0.03 gram of phosphorus, etc. If there are less than 19 grams of carbohydrate, there must necessarily be less than 100 grams of new tissue produced. Similarly, if the nitrogen or phosphorus or any other ingredient is lacking or inadequate in amount, it becomes a limiting factor to new growth. Theoretically, any one of the essential nutrients may be deficient in amount or unavailable in form; in reality all have been found to be limiting factors somewhere, at some time, or with some plant. Practically, however, there is ample evidence to show that the available nitrogen supply (that is, nitrates) is a limiting factor more frequently than is any of the other nutrients. Consequently the carbohydrate-nitrogen relationship $\left(C/N\right)$ is more important than any, or perhaps all, of the others in determining whether the plant is to use up its supply of carbohydrates in making new growth or is to accumulate them in the form of a stored surplus. Therefore, more attention will be devoted to a discussion of this particular relationship than to any of the others.

If temperature is favorable and soil moisture supply is adequate for vegetative growth (cell division, increase in bulk, tissue differentiation, etc.), the bulk of the carbohydrate supply that is on hand and the daily increments that are being currently manufactured *will not be utilized* for new vegetative growth, provided there is an extremely limited nitrogen supply — a C/N relationship. This condition will occasion further carbohydrate accumulation and still further promote fruitfulness. On the other hand, with a large nitrogen supply giving rise to a ${\large C}/_{N}$ relationship, new vegetative growth will be stimulated, and carbohydrates will be promptly utilized, with fruitfulness reduced, delayed, or inhibited. Theoretically, at least (some exceptions will be pointed out later), changing the plant from a weakly vegetative, non-flower-bearing growing condition to a somewhat more vigorously vegetative moderately productive state and finally to an over-vigorous nonproductive condition, depends on the ability to change its carbohydrate-nitrogen relationship from ${}^{\small C}/_{\small N}$ to ${}^{C}/_{N}$ to ${\large C}/_{\small N}$ to ${\large C}/_{N}$.

As was pointed out in Chapter X, the plant-grower's influence over the manufacture, the utilization, and the plant's content of carbohydrates is indirect and imperfect. However, control over the plant's nitrogen supply and therefore content is more direct and certain. Consequently, the grower has carbohydrate-nitrogen relationship under fairly ready control, and he can to a considerable extent direct the plant's activities into vegetative or reproductive growth, as follows:

1. The plant in the weakly vegetative condition with both carbohydrate and nitrogen content at a low level $\left({}^{\small C}/_{\small N}\right)$ can be changed to a weakly fruitful or productive condition $\left({}^{C}/_{N}\right)$ by an increase in its supply of nitrate nitrogen. This is usually most readily accomplished through the application of quickly available nitrogen-containing fertilizers, such as nitrate of soda or sulphate of ammonia. Incidentally, such a procedure usually results in a rather prompt increase in the plant's supply of carbohydrates, both through accelerating the rate of their manufacture by the leaves and through increasing leaf number and area. This, in turn, calls for more nitrate nitrogen if the new nutritive relationship is to be maintained. The net result is that the nutritional level of the plant is raised (represented crudely by the fraction ${\large C}/_{N}$).

2. A still greater degree of fruitfulness may be obtained by the temporary use of larger amounts of nitrate nitrogen to promote for a short period a very rapid vegetative growth, and then withdrawing further nitrogen supplies. The large nitrogen supply and its associated rapid vegetative growth are characterized by

a carbohydrate-nitrogen relationship in which there is a medium quantity of carbohydrate and a large amount of nitrogen $\left({}^{C}/_{N}\right)$, followed promptly by a diminishing nitrate content and an increasingly large carbohydrate content $\left({}^{C}/_{N}\right)$.

3. If, however, the nitrogen supply is not withdrawn, but increased instead, bringing about a lower carbohydrate-nitrogen ratio ${}^{C}/_{N}$ through the utilization of the carbohydrates, the overvigorous vegetative condition is brought about. The condition the plant is in, in respect to its carbohydrate-nitrogen relationship, can be judged by its appearance and behavior. That relationship can then be maintained or altered most readily by fertilizer applications or other soil treatments that influence its nitrate-nitrogen content.

Perhaps the influence of the carbohydrate-nitrogen relationship, as explained in the preceding paragraphs, has been somewhat exaggerated in order to make clear the principle, and its control by the plant-grower has been made to appear somewhat easier than it sometimes is. Some of the limitations of the principle, and some of the practical difficulties in effecting changes in the ratio will be pointed out a little later. However, the maintenance of the balance between vegetative growth on the one hand and the initiation and orderly continuation of the reproductive processes on the other or the shifting of that balance so as to obtain only vegetative growth in some cases or only flowering, fruit and seed production at other times, is important in the everyday culture of horticultural plants. Every grower needs to understand the principles upon which the balance rests, and as much as possible about how various practices may be employed to change it.

FACTORS LIMITING THE INFLUENCE OF NUTRIENT RELATIONSHIPS

As has just been explained, nutrient relationships, and especially the carbohydrate-nitrogen relationship, are important in determining whether a plant will make vegetative growth or turn its energies into the production of flowers, fruits, and seeds. However, it should be recognized that other conditions, both external and internal, likewise influence the direction or type of growth, and often they are the determining factors. Included among these are: (1) size of plant and quantity of reserve or surplus food materials, more or less regardless of the relationships or proportions of the several kinds of food and nutrients; (2) available moisture supply; and (3) length of day.

Germination of the seed is itself a vegetative process, and this must always be followed by a considerable amount of additional vegetative growth before reproduction is possible. The amount and likewise the duration of this post-germination vegetative growth that must precede reproduction vary greatly, not only with kind of plant but with environmental conditions. Days or weeks must elapse between germination and flowering, or even the initiation of the flowering process, in the case of annuals; weeks or months, in biennials; months or years, in perennials.

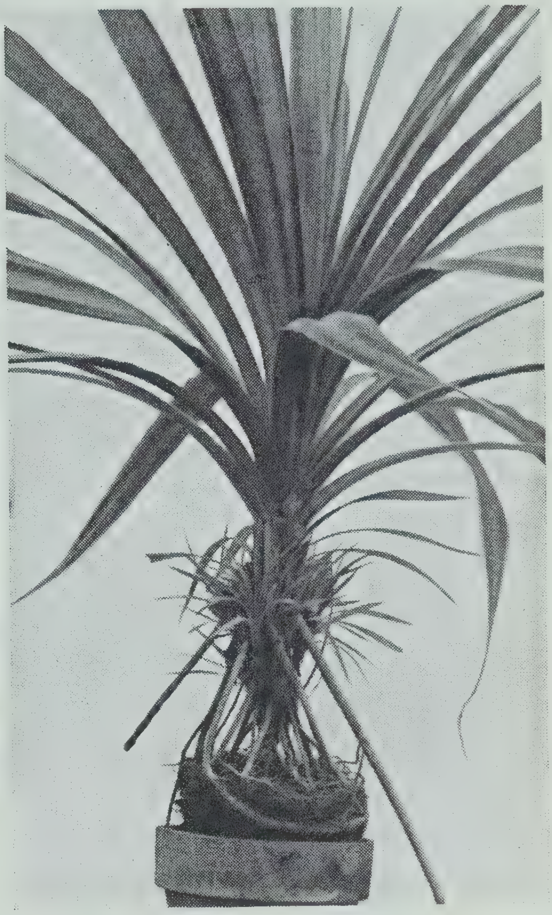
FIG. 78. A screw pine (*Pandanus veitchii*) that has been growing so long in the pot in which it is pictured that it has become extremely pot-bound. Indeed, the root mass has more or less crowded the plant out of its pot. Nevertheless, the plant has never developed flower buds and flowers, in spite of having possessed at one time or another a nutritive condition (that is, a carbohydrate-nitrogen balance) similar to that which plants of this species have when, upon attaining mature size, they do come into flower.

The century plant (*Agave americana*) or screw pine (*Pandanus utilis*) or cocoanut palm (*Cocos nucifera*) cannot be made to flower when only a year or two years or perhaps even ten years old, though through special cultural treatments the same nutrient relationships can be brought about in them as occur when they naturally become fruitful. Perhaps such treatments will bring them into flowering at an earlier age when they are only half or quarter as large as when this process normally occurs, but flowering is nonetheless conditioned on a certain quantitative development, a certain size or stature (see Figure 78). A

Northern Spy apple tree can be so grown and handled that at five or six years of age it will present essentially the same carbohydrate-nitrogen relationship as it usually does at fifteen or sixteen years of age or as does a Wealthy or Wagener tree at the five- or six-year age; however, it does not become fruitful until years later. Through the artificial regulation of its nutrient, moisture, and light supply and of temperature a six- or eight-inch-tall corn plant of a standard tall-growing variety can be made to present the same nutrient relationship in late June that the six- or eight-foot plant of the same variety normally presents six or eight weeks later, but it does not promptly tassel out and begin ear formation at the earlier date. Some of the bamboos present an even more extreme — and puzzling — illustration of failure to differentiate flower buds, to produce flowers, and set and mature fruits and seeds than those just cited, when presumably they have developed or acquired a certain balance between carbohydrate and nitrogen content. They continue to produce vegetative growth only for many decades; then all the individuals over a large area blossom and seed at one time. Their vegetative growth and blossoming are synchronized. It is almost inconceivable that many thousands of individual culms, of varying age and size, distributed over a wide area, should suddenly develop the same carbohydrate-nitrogen relationship or that no one of them should have developed such a relationship previous to that time.

In the chapter on "Water as a Limiting Factor" it was pointed out that any and all growth depends on a certain minimum moisture supply. Under conditions of severe drought growth may cease, and regardless of nutrient relationships, neither vegetative development nor reproduction takes place. If less extreme, drought may serve even in the presence of much available nitrogen, to check vegetative growth, and permit an accumulation of carbohydrates that, in turn, will lead to fruitfulness.

Perhaps even more important than moisture supply in setting limits to the operation of nutrient relationships in directing growth into vegetative or reproductive channels is length of daily exposure to light. This subject is discussed in some detail under the heading of *photoperiodism* in the chapter on "Light as a Limiting Factor" and illustrated in Figure 79. So-called *short-day* plants remain vegetative as long as the day length is eleven or twelve hours or more, and they may never flower and fruit if grown in

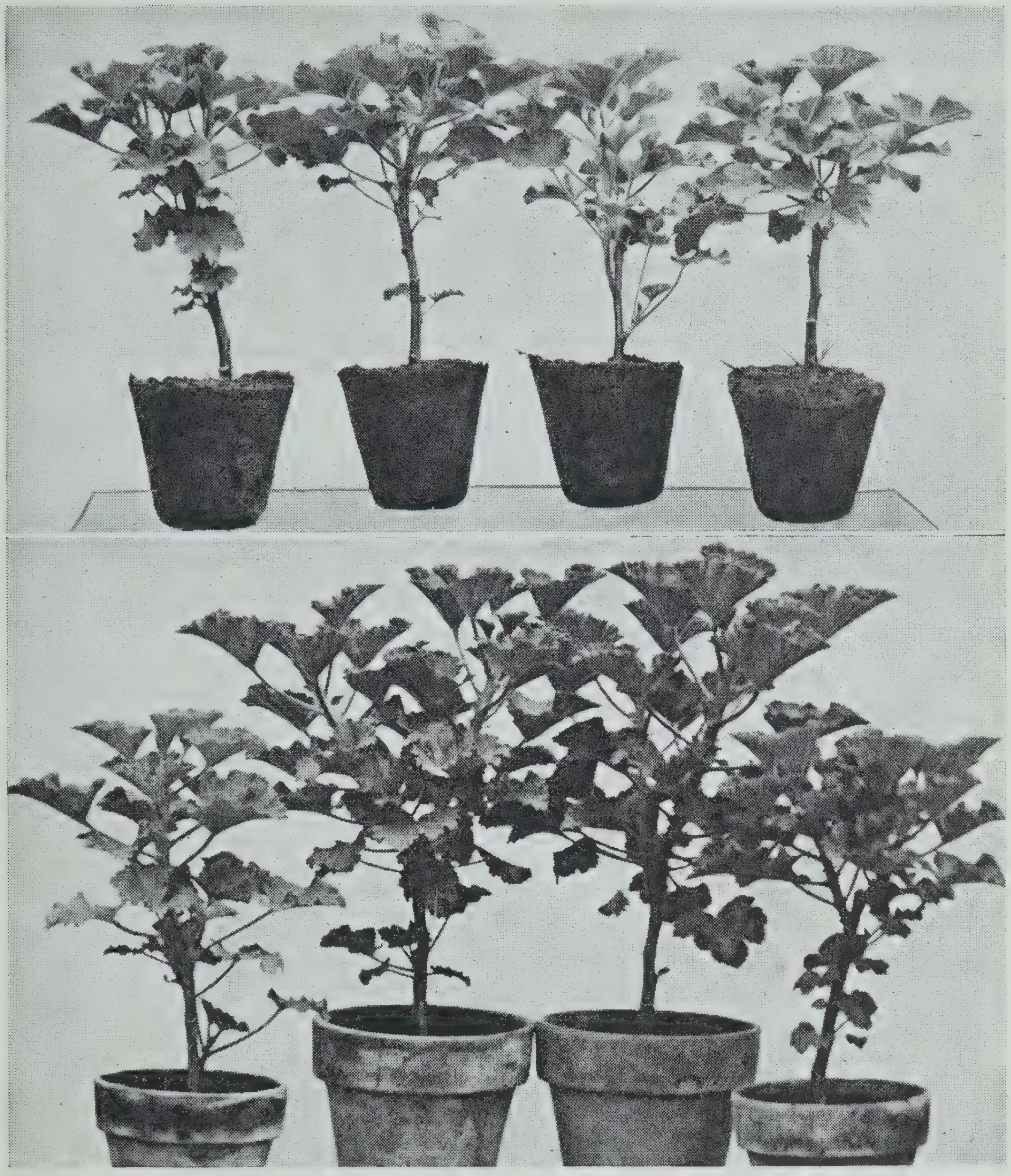

Fig. 79. Above are shown four *Pelargonium* plants, lifted from their pots and photographed just as they were becoming pot-bound. Two were returned to their pots, and two were shifted to pots of a larger size. The four plants, as they appeared six weeks later, are shown below. Note that while two have grown rapidly, the other two have remained about the same size as they were. Neither pair has developed flowers, flower-bud formation in this species depending on longer days than those to which these plants were exposed.

equatorial regions, regardless of their nutrient conditions. On the other hand, some of the long-day plants requiring daylight periods of fifteen to sixteen hours for the initiation of their reproductive processes, may remain permanently vegetative in regions where day length never exceeds twelve to thirteen hours.

Finally there is a number of varieties of plants (for example, the Madame Salleron variety of *Pelargonium zonale*) that for some unknown reason never produce seeds or even flowers. Changing their nutritive relationships affects their vegetative growth as do similar changes in the nutritive relationships of other plants, but the relationships that cause the initiation of the reproductive processes in most plants have no such influence upon them.

Vegetative growth on the one hand and fruitfulness on the other are thus seen to depend on a combination of several favorable conditions or factors rather than the presence or absence of a single one. The nutrient relationship is perhaps the determining or limiting factor more frequently than the others, and certainly it is the one most completely under the grower's control, and therefore his most convenient tool in making his plants more or less vegetative or more or less fruitful.

VEGETATIVE AND REPRODUCTIVE OBJECTIVES IN GROWING PLANTS

The majority of crop plants are grown for their flowers, fruits, or seeds rather than for their vegetative parts and in this chapter there has perhaps been the implication that vegetative growth is a more or less necessary evil, incident to the later production of the tissues and organs associated with reproduction. This, in turn, implies that sooner or later in the culture of nearly all plants such nutritive relationships will be developed and such other conditions provided that maximum fruitfulness will be promoted, following or coincident with the slowing down and final cessation of vegetative growth. This, however, is not always the case. Many ornamental plants, for example, the crotons, *Coleus*, the Colorado blue spruce (*Picea pungens*), and most of the Junipers, are cultivated primarily, or even exclusively, for their foliage; the same statement holds for the commercial tea plant (*Thea sinensis*); asparagus and rhubarb are grown for their young, tender stems and leaf petioles; spinach is grown for its leaf blades; horse-radish and carrots are grown for their roots; the cork oak (*Quercus suber*) is grown for its bark; *Hevea brasiliensis* is grown for its latex from which rubber is made; the long-leaf pine (*Pinus palustris*) is valued more for its resinous sap from which turpentine and rosin are distilled than for its timber; and finally the timber of forest trees, whether used for fuel or sawed into lumber, is vegetative tissue pure and simple. With these and almost numberless other crop plants it is only vegetative organs and tissues that man values and in which he is primarily interested. If these plants would, or could, be made to turn all their energies and resources into vegetative growth, except perhaps for the occasional production of enough seeds for establishing new plantations, the objectives of a horticulturist or forester would be the better served. Consequently in the culture of these plants the best procedure is to see that they are more or less continuously (except perhaps for such matters as "hardening off" to prepare for cold weather or drought) provided with a carbohydrate-nitrogen balance and other conditions, that tend to force the prompt utilization of carbohydrates in making new growth. Only through this procedure will maximum crop yields be obtained.

Contrasting sharply with this situation is one in which the objective is a very minimum of vegetative growth and a maximum of flowering and fruit and seed production. This is illustrated in certain plants, such as sweet alyssum (*Alyssum maritimum*) or lobelia, used for the "edging" of flower beds, or the papaya (*Carica papaya*) which is grown in the tropics for its fruit. In the former what is wanted is a mass of flowers that as nearly as possible completely hides the compact limited vegetative growth beneath; in the latter increase in height of the single-stemmed plant and the formation of new leaves function principally to provide new nodes from which new flowers and fruits can develop. Cultural conditions and nutritive (carbohydrate-nitrogen) relationships that would promote a really vigorous vegetative growth in such plants would in the main defeat the purposes for which they are cultivated.

Between these extremes lies the great majority of crop plants in which the grower's objective is something between extreme vegetation on the one hand and extreme fruitfulness on the other. Rhododendrons and magnolias are valued hardly less for their beautiful glossy foliage during eleven months of the year than for their gorgeous display of flowers during the twelfth month. With many, if not most kinds, in this general class of crop plants are those in which the flowers, fruits, or seeds constitute the crop that is harvested, but both their size and quality are closely correlated with the amount of vegetative growth. Maximum flower production in the lilac or crape myrtle (*Lagerstroemia indica*) or the flamboyant (*Poinciana regia*) or maximum fruit production in the apple or orange or seed production in corn or coffee on either a single plant or an acre basis may not accompany maximum shrub, tree, or plant size, but neither are these qualities associated with small plant size. Within certain limits plant vigor and size on the one hand are positively correlated with flower, fruit, and seed yield on the other, and at least a moderately vigorous growth and moderate size are wanted. With such plants, therefore, the best procedure is, first, through the proper combination of cultural treatments, to provide a nutritive (carbohydrate-nitrogen) balance such that vegetative growth is rapid and vigorous; then it should be changed rather quickly to one in which vegetative growth is checked and maximum fruitfulness promoted. In the tomato or cantaloupe this would mean providing a nitrogen-rich soil early in the growing season but having the available nitrate supply taper off sharply in midseason so that, once a large plant is produced, the plant does not continue to run to vine but comes into heavy production.

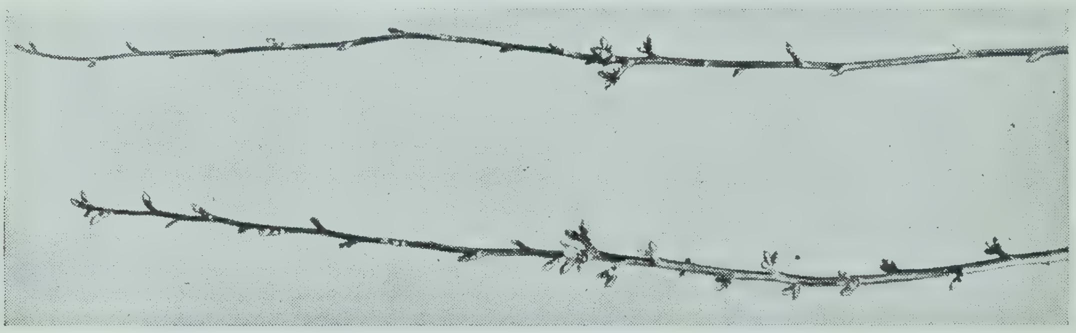

Fig. 80. These two cherry shoots were photographed in the autumn. Both are representative of the trees that produced them. Both grew vigorously the preceding spring and early summer. The tree from which the upper shoot was taken was partly defoliated in early summer as a result of leaf-spot attack. The other retained its foliage until late fall. Note the difference in shoot diameter and in flower-bud formation, associated with the influence of leaves on carbohydrate manufacture and storage.

In an herbaceous perennial, such as the hardy chrysanthemum that flowers in early fall, it means following this procedure year after year. For maximum production in the strawberry, which makes a limited amount of vegetative growth and flowers and matures fruit in late spring (extending into early summer in northern sections), then produces most of its vegetative growth in the summer months, and finally forms flower buds for next year's crop in the fall, it means providing a rather high carbohydrate-nitrogen relationship $\left(\mathrm{C}/\mathrm{N}\right)$ in the spring, a lower one $\left({}^{\mathrm{C}}/\mathrm{N}\right)$ during the summer and a much higher one $\left(\mathrm{C}/_{\mathrm{N}}\right)$ during the fall months. The apple and pear call for a sharply decreasing carbohydrate-nitrogen relationship $\left(\mathrm{C}/_{\mathrm{N}} \text{ to } \mathrm{C}/\mathrm{N}\right)$ as growth starts and during flowering and the fruit-setting period in the spring and continuance of this low relationship during the flush of spring growth (until July 1 to 10). Then there should be a sharp shift to a rather high relationship $\left(\mathrm{C}/_{\mathrm{N}}\right)$ in July while flower buds for the next year's crop are being formed, maintenance of this condition or perhaps some trend to a lower ratio while the fruit crop is developing. Finally there should be an effort to develop a high relationship $\left(\mathrm{C}/_{\mathrm{N}}\right)$ in the fall to aid in the thorough ripening of the fruit and maturing of the wood before winter and the accumulation of ample reserves for next spring's growth.

With other perennial crops the demands for a changing nutritive balance are similar or different, depending on the kind of plant and its seasonal life history (that is, when it flowers, when it matures its crop, when it makes the most of its vegetative growth, whether or not it has special vegetative storage organs such as tubers or bulbs, to what extent it must be "hardened" for winter, etc.). Most plants will make some vegetative growth and perhaps bear some flowers, fruits, and seeds if totally neglected or in spite of almost anything the grower ordinarily does or is likely to do. However, whether or not the grower is successful in obtaining the best possible results with his crop plants depends largely on his knowledge of their changing requirements as the season advances to make them relatively more reproductive. It also depends on his ability so to adjust and manipulate his cultural treatments as to bring about the optimum internal nutrient relationships and conditions from time to time.

PROBLEMS

1. Fruit trees are sometimes propagated on *dwarfing* roots and the resulting dwarf trees come into bearing at an earlier age than those grown on *standard* stocks. How do you explain this effect on the basis of a carbohydrate-nitrogen relationship?

2. Do you think that permitting a greenhouse or house plant to become pot-bound would hasten or delay flowering? Why?

3. Would the effect of growing sod ground cover in an orchard tend to promote and maintain a higher or lower carbohydrate-nitrogen nutritive relationship? Explain why.

4. Flower production is at its lowest level in the greenhouses of the northern states during the short-day cloudy winter months. Would you expect that more abundant flower production would be promoted by using relatively more or relatively less nitrogenous fertilizer at that time than is customary in early fall or late spring? Why?

5. Would you recommend the same fertilizer application (particularly in respect to amounts and forms of nitrogen) for a very early maturing variety of some crop (for example, tomatoes or sweet corn) as you would for a very late maturing variety of the same crop? Explain.

6. Why do trees that have been partially girdled by mice or rabbits set heavy crops the succeeding year, if they live?

7. Is the carbohydrate-nitrogen relationship a function of the plant or of the soil or of both or of neither one? Explain.

8. Would the seasonal changes in the carbohydrate-nitrogen balance that you would consider ideal in the culture and development of celery be the same or different from those you would consider ideal for the potato? Why? Explain fully.

CHAPTER XII

FLOWER-BUD DIFFERENTIATION AND FLOWERING HABITS

IN THE last chapter the terms *fruitfulness* and *fruitful condition* were used repeatedly to refer to a stage in the normal development or life history of all plants (except for those that never produce flowers and seeds) when vegetative growth slows down or even ceases, and flowers, fruits, and seeds are formed. The production of seeds is, of course, the objective (or, perhaps more accurately, the means to the end) in the reproductive process, but fruits must develop before seeds can mature. In turn, flowers must open, be pollinated and set before the fruits can even start to develop.

To the casual observer the flower is the beginning of the reproductive process. The flower, however, is only the fully opened flower bud — a bud that may have been formed days, weeks, or even months earlier. The reproductive process had its real beginning when the embryo flower parts were first formed, or as we say, *differentiated*, in the bud. That is the really critical stage in the delicate balance between vegetation and reproduction from the standpoint of the future direction of the plant's growth; once the embryo flower parts are formed, the subsequent growth and development into flowers, fruit, and seed are more or less automatic and assured — at least, possible. If they are not formed, that plant must necessarily continue to make vegetative growth only. For this reason both the anatomical and physiological changes associated with flower-bud *initiation* have been the subject of much study. Much information has been obtained as to when the initiation or differentiation of these buds occurs in different species and varieties, the rate and character of subsequent development, and the way in which it may be influenced by various environmental conditions and cultural practices.

ANATOMICAL AND MORPHOLOGICAL CHANGES IN FLOWER-BUD DIFFERENTIATION

As defined in Chapter III, a bud consists of a very short central axis or stem, often about as broad as long, with regularly spaced joints or nodes, surrounded and enclosed by a number of overlapping scales or bracts. Except in its very early stages of development this embryo or rudimentary stem shows some differentiation of tissues (for example, epidermal and subepidermal) and even of young organs (for example, young leaves). Typically it has a conical or bluntly rounded tip or growing point, as shown at the left in Figure 81, and the tissue in this growing region is meristematic in type. As the bud grows out into a branch, its tip is carried out farther and farther from the point where it started in the bud. It continues to be protected by later-formed scales or by infolding leaves or leaf petioles, and examination shows that structurally the tip closely resembles its antecedent in the bud (see Figure 20). In the meantime other structures (lateral buds) that are the counterparts of the shoot tip have been developing in the axils of the shoot's leaves.

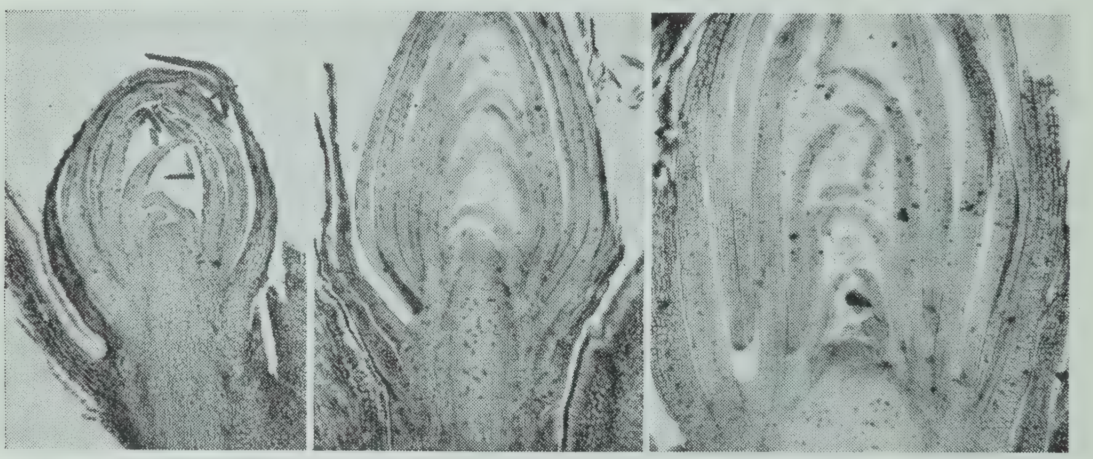

FIG. 81. Buds of the Montmorency cherry. At the left a newly formed leaf bud (June 15th); in the center a fully formed leaf bud (July 15th); at the right a bud showing the initial stages of flower-bud differentiation, indicated by a broadening and flattening out of the growing point (July 20th). (Magnified twenty-five diameters.)

As long as the plant as a whole or the branch in question remains vegetative, its terminal growing point and its lateral buds, as seen under the microscope, present the general appearance that has been described. Preceding or coincident with the general slowing down of vegetative growth that is associated with the change from the vegetative to the fruitful condition, there is usually a cessation in length growth at the tip of the stem axis, an increase in its diameter, and a flattening out of its pointed or conical crown. Sometimes these changes *within* the bud are accompanied by a thickening of the entire bud with its bud scales that is evident to the naked eye; in other instances they are not. These morphological and anatomical changes are known as *flower-bud initiation.* The development of the inflorescence and flower parts within the bud, which follows more or less promptly, is *flower-bud* and *flower*

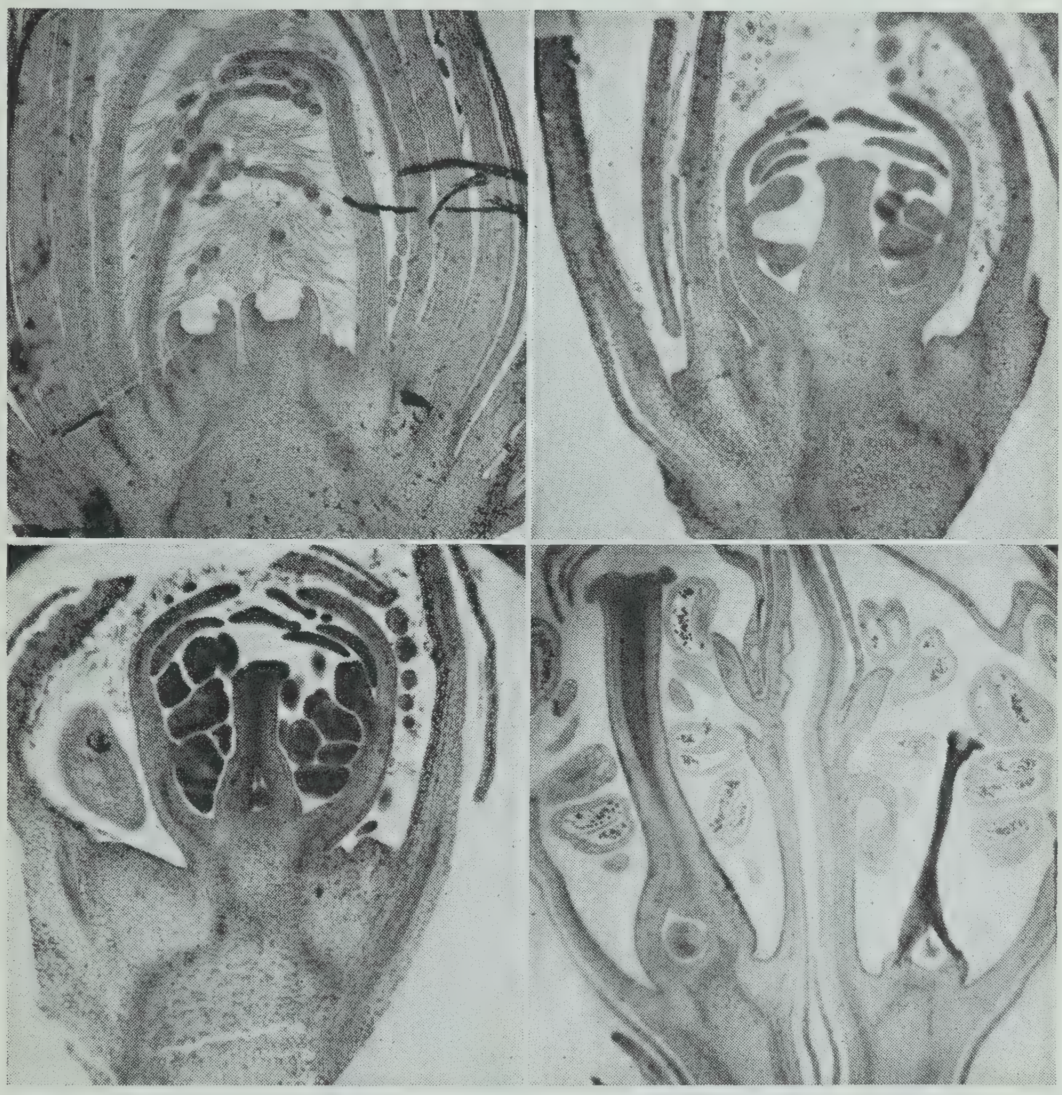

Fig. 82. Progressive stages in flower-bud differentiation and development in the Montmorency cherry. Upper left taken August 10, magnified thirty-three diameters; upper right taken November 9, magnified thirty-three diameters; lower left taken March 28, magnified thirty-three diameters; lower right taken April 29 and showing one live flower bud and one killed a week earlier by frost, magnified twelve diameters.

differentiation. Successive changes in this process of the initiation of the reproductive phase of the plant and differentiation of the organs of reproduction, as illustrated in the cherry, are shown in Figures 81 and 82.

The flower bud is thus seen to have its origin in a vegetative, or leaf, bud. That is, in their earliest stages all of the plant's buds are vegetative in character. Most of them continue as leaf buds until they start to open, and then they grow out into vegetative branches. Should they become latent, they remain vegetative in character indefinitely. This is evidenced by the fact that when latent buds are forced out into growth, they give rise to vegetative organs. On the other hand, in its youth every bud is potentially a flower bud. That is, there is the possibility that when a certain stage of development is reached, and *if nutritive and certain other conditions are favorable*, it may develop into a flower bud. In so doing the bud loses its vegetative character, and so far as we know, it cannot revert or change back to its former condition.

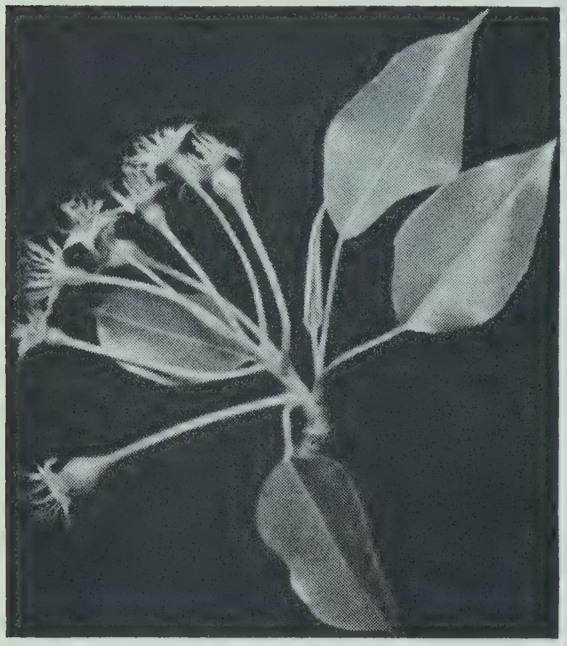

FIG. 83. A pear spur that has borne a terminal cluster of flowers, two or three of which appear to be setting fruit. Note that there are two leaves attached to the peduncle of the flower cluster and that at the right the spur is making a lateral vegetative branch. Flowers, leaves, and shoot are all derived from the single mixed terminal bud of the spur, such as are shown in Figure 85.

The inference that might be drawn from these last statements is that flower buds contain only the rudiments of flower clusters and flowers, just as leaf buds contain only the rudiments of vegetative organs. This is true in many plants, as in the flower buds of the cherry shown in Figure 82. On the other hand, the so-called *flower* buds of many other plants are in reality *mixed* buds. That is, while they are differentiating flower clusters and flowers, they are likewise forming rudimentary vegetative organs (stems and leaves), and when the bud opens or unfolds, it produces a leafy flower cluster or a flowering shoot. The unfolded mixed flower bud of the pear is shown in Figure 83. For the initiation of the reproductive process in plants having mixed flower buds, essentially the same conditions must be provided as in the case of plants whose flower buds contain flowers only. The subsequent processes of flower cluster and flower development likewise follow the same pattern.

SPECIES AND VARIETY DIFFERENCES IN SEASON OF FLOWER-BUD FORMATION

In the preceding chapter on "Growth and Fruitfulness" the fact was brought out that the change from a vegetative to a fruitful condition depends on: (1) the accumulation of carbohydrates and the development of a high carbohydrate-nitrogen balance $\left(\mathrm{C}/_{\mathrm{N}}\right)$, and (2) the presence of certain other none-too-well-understood factors or conditions. If it depended solely on a certain balance between the principal food and nutrient constituents, such as carbohydrates and nitrates, it could take place whenever that balance is attained, or perhaps approximated. Yet we know that it doesn't, for flower-bud initiation is an unmistakable evidence of the change from a vegetative to a reproductive phase, and in most plants flower buds are differentiated only at certain definite, specific periods or seasons. We, therefore, recognize the operation of "certain other factors," and the fact that the process itself is closely correlated with *season of the year* strongly suggests photoperiodism as a controlling factor second in importance only to nutritional condition. Thus, certain chrysanthemum varieties continue to develop crown buds and flowering stems as long as the days are twelve hours or more in length. When the days are shorter (and this length of day period varies with varieties), crown-bud and new stem formation ceases, and true flower buds are formed terminally and subterminally in the leaf axils. There apparently is no time during the growing season, however, when flower-bud initiation is not occurring in plants of some kind. We do not, therefore, have a definite photoperiod for flower-bud initiation *as a plant process*, as we do a definite wilting point for water absorption from a certain soil; instead we have a series of photoperiods in different plants, comparable to the wide range of temperatures that constitute the thermal death points for their tissues. As with thermal death points, where for some plants the critical temperature is invariably a certain very narrow range (for example, 31° to 33° F.), whereas for others it is a rather wide range (for example, 0° to − 10° F.), depending on conditions, so it is with seasons of year for differentiating flower buds. In some species and varieties differentiation all takes place within a few weeks, or even days, in others it may take place any time within a considerably longer period, or perhaps at any time during the year.

In annuals flower-bud initiation necessarily follows rather promptly the completion of a certain amount of vegetative growth — otherwise, no seeds would be matured, and the plant could not reproduce. In some of the shorter-lived annuals less than a month may elapse between germination and the formation of flower buds. With a great many annuals the attainment of a certain minimum size and of a certain internal nutritive condition or balance seems to have greater influence on time of flower-bud formation than does season or photoperiod. They may flower and mature seed in April or June or August or October, depending largely on when their seeds germinated and how rapidly they grew. Some kinds with more or less of an indeterminate type of growth differentiate flower buds early in the season when they have attained a certain minimum size; then, as they make more vegetative growth, they form more flower buds and flowers, and this process continues throughout the growing season. The tomato, watermelon, and petunia are plants having this habit. There are other annuals, however, that normally form flower buds only within comparatively short periods. Thus, in northern sections most species of violet (for example, *Viola sepincola*) blossom only in May and June from flower buds formed in early spring (or perhaps the fall before). Few or no flowers open in midsummer, though pollination and fertilization (*cleistogamous*) may take place in some of the unopened buds, and seeds will be formed.

In most biennials and perennials flower-bud initiation is restricted to shorter periods. Thus, in the strawberry (except for the so-called *ever-bearing* kinds) flower-bud initiation generally occurs in late September and early October in the northern states; in most raspberries with biennial canes it takes place in late winter and early spring; in those raspberries or related types of brambles with annual canes (for example, *Rubus chamaemorus*) it takes place in midsummer; in the grape it takes place mainly in late June and early July; in the orange in Florida it takes place in late January and February. In the walnut and pecan differentiation of the staminate flowers that open in the spring takes place early in the preceding summer; differentiation of their pistillate flowers occurs in early spring just prior to their opening. There are endless other variations presented by other plants.

Knowledge as to the seasons or periods when his plants initiate flower buds is important to the grower principally for the reason that an effort should be made to provide for them at and shortly previous to that time those conditions that favor the formation of a reasonably large, if not a maximum, number. Failure at that season can hardly be compensated for by any amount of care during the remainder of the year. This matter is of special importance with perennials and especially with trees, shrubs, and vines.

FLOWERING AND FRUITING HABITS

In Chapter III it was stated that buds develop in three different locations: (*a*) *terminal*, at the ends of stems or their branches; (*b*) *lateral*, in the axils of the leaves at the nodes along the sides of stems or their branches; and (*c*) *adventitious*, at some other place such as an internode (as in the red bud shown in Figure 84) or on callus tissue or on the roots or leaves. A statement has also been made in the discussion of flower-bud formation that potentially every bud is a flower bud, though only a small percentage of the total ever differentiate floral structures. It follows, therefore, that flower buds may be terminal, lateral, or adventitious. In many

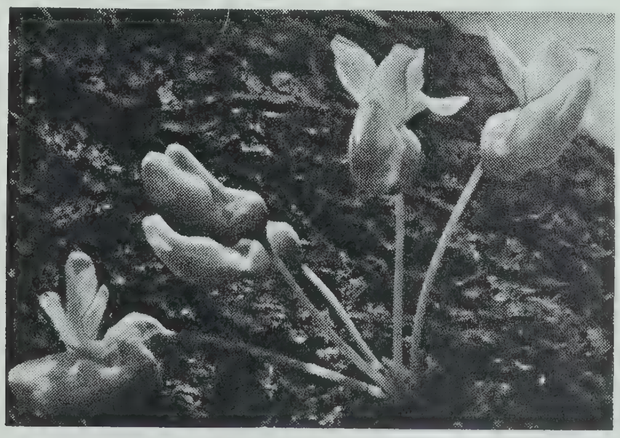

FIG. 84. Flowers developing from an adventitious bud on an old limb of the Judas or red-bud tree (*Cercis canadensis*).

species (for example, the oaks, the peach, the black raspberry, the sweet pea) adventitious buds are seldom formed. In them flower-bud formation is thus naturally limited to terminal and lateral buds. In reality, however, the limitations as to where flower buds are actually formed go much further, and these limitations make possible a classification of plants in respect to their flower-bearing and fruit-bearing habits that is found very useful.

SHOOT AND SPUR FLOWERING AND FRUITING

Comparatively long branches of the current season's growth are called *shoots;* short branches may likewise be shoots but in many plants they are called *spurs*, especially if they are rather thick and stocky. There is, however, no clear sharp line between shoots and spurs; branches more or less intermediate in type may be called *shoots* by one and *spurs* by another with equal propriety. Since the buds on both types of branches may differentiate flower parts, we have both shoot and spur flowering, shoot and spur fruiting. Annuals, biennials, and herbaceous perennials are less inclined than woody perennials to form short stocky branches that are commonly classed as spurs. Their short branches are likely to be rather slender and are thought of as short shoots. Consequently their flowering and fruiting is principally on shoots. Many woody plants, for example, the grapes, likewise form few or no spurs, and their flowering and fruiting is entirely on shoots.[1] On the other hand, the great majority of woody plants normally produce both shoots and spurs. In some kinds, for example, the lilac (*Syringa vulgaris*) and the Japanese persimmon (*Diospyros kaki*), flowering and fruiting are only on shoots; in others, for example, the loquat (*Eriobotrya japonica*) and sweet cherry (*Prunus avium*), flowering and fruiting are almost exclusively on spurs; in still others, for example, golden bell (*Forsythia suspensa fortunei*), the sour cherry (*Prunus cerasus*), and elm (*Ulmus americana*) flowers and fruits are borne on both shoots and spurs.

TERMINAL AND LATERAL FLOWERING AND FRUITING

Both shoots and spurs have terminal and lateral buds, and consequently it is possible for the plants that differentiate their flower buds on either type of stem or branch to form them terminally or in the axils of their leaves. In reality, they are formed in both places, though generally a single species or variety characteristically forms them in only one location. Thus, most of the flower buds of the sweet cherry are formed laterally on spurs, those of the raspberry laterally on shoots, those of the apple and pear (for the most part) terminally on spurs (Figure 85), those of the Polyantha roses, the sunflower (*Helianthus annuus*), and snapdragon (*Antirrhinum majus*) terminally on shoots (Figure 86). Many other species and varieties exhibit various combinations of terminal and lateral flower-bud formation and flowering. For instance, in maize the male inflorescence is borne terminally, the pistillate inflorescence laterally, on the main stem; in the walnut and pecan the reverse situation is found, the pistillate inflorescence being borne terminally and the staminate inflorescence laterally on the branches. In

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[1] The literature of grape-growing, especially that pertaining to fruiting habits and pruning, is full of references to spurs and spur bearing, but the "spurs" are in reality the basal portions of shoots that have been shortened back in the pruning process to a point where they more or less resemble the spurs of true spur-forming plants.

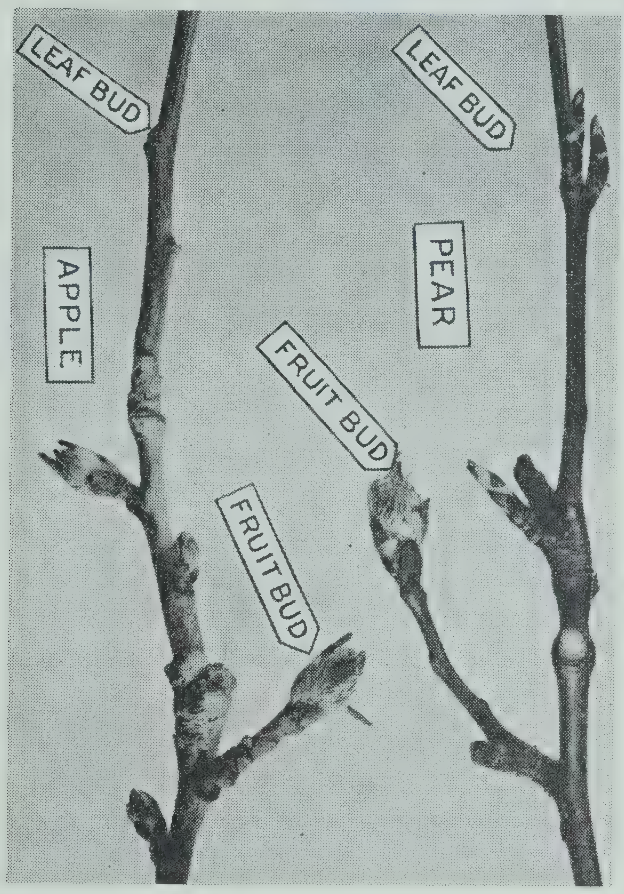


Fig. 85. Small flowering branches of the apple and pear photographed as the buds were just about to open in the spring. Note the difference in size and shape between leaf buds and flower buds. Note also that the flower buds are terminal on short spurs.

general, the terminal flowering habit, especially where the flower buds terminate shoots, results in a more compact type of growth than does the lateral flowering habit. The first condition, that is, with the flower cluster terminating the shoot, is called a *determinate* and the other an *indeterminate* flowering habit.

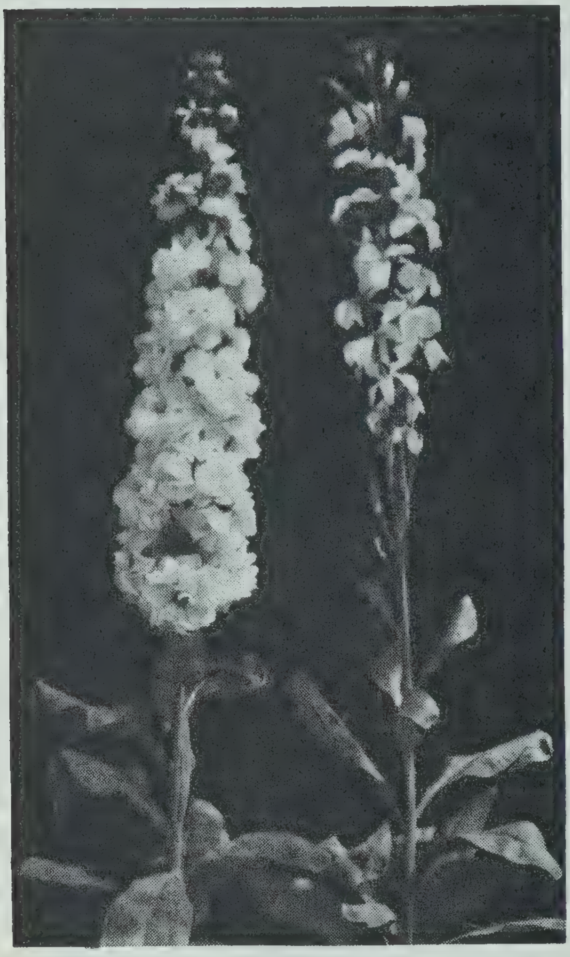


Fig. 86. Flowering spikes of the stock (*Mathiola incana*) showing typical terminal flowering of the indeterminate type. The spike on the left is bearing double and the one on the right single flowers. Both are of the same variety.

Just why some kinds of plants fail to produce short, thick branches that we call *spurs*, while other kinds produce them, or why only the terminal spur buds of some kinds differentiate flower parts, while in others only their lateral spur buds and in still others their lateral shoot buds do so, is not known. These distinctive flowering and fruiting habits apparently are the expression of inherited tendencies and characteristics.

FIXED BEARING HABITS

The statement has been made that every axillary and terminal bud that the plant forms is potentially a flower bud, though actual differentiation of flower parts depends on the presence of certain favorable conditions. In some plants flower-bud formation takes place, apparently, regardless of conditions. For instance, in the cucumber (*Cucumis sativus*) flower buds and flowers are formed at every node (see Figure 87), though the pistillate flowers from which the fruits develop are borne only at more or less irregular intervals. This holds for the weakest and most vigorous plants as well as those in a more normal, intermediate condition. Either their differentiation is independent of nutritive conditions, or it takes place through as wide a range of nutritive conditions as can be produced by the most extreme cultural treatments. In either case what the situation amounts to is the same — a constant or fixed flowering habit. Furthermore, in some plants flower buds are regularly formed at definite points other than in leaf axils or at the ends of shoots or spurs. Thus, in most varieties of the common garden tomato (*Lycopersicon esculentum*) the flower buds are formed on the main stems or branches opposite to (and perhaps slightly above) every fifth or sixth leaf. Some of these may abscise at an early stage, the full development of the flower clusters and flowers depending on favorable nutritive and environmental conditions; nevertheless, regardless of conditions, the early stages of the reproductive structures will be formed at regular intervals. In the cherry tomato (*Lycopersicon pimpinellifolium*) there is a similar development of flower clusters and flower parts, except that they characteristically appear opposite every third leaf. Many other kinds of plants similarly display a very marked uniformity and regularity in their flower-, fruit-, and seed-bearing habits.

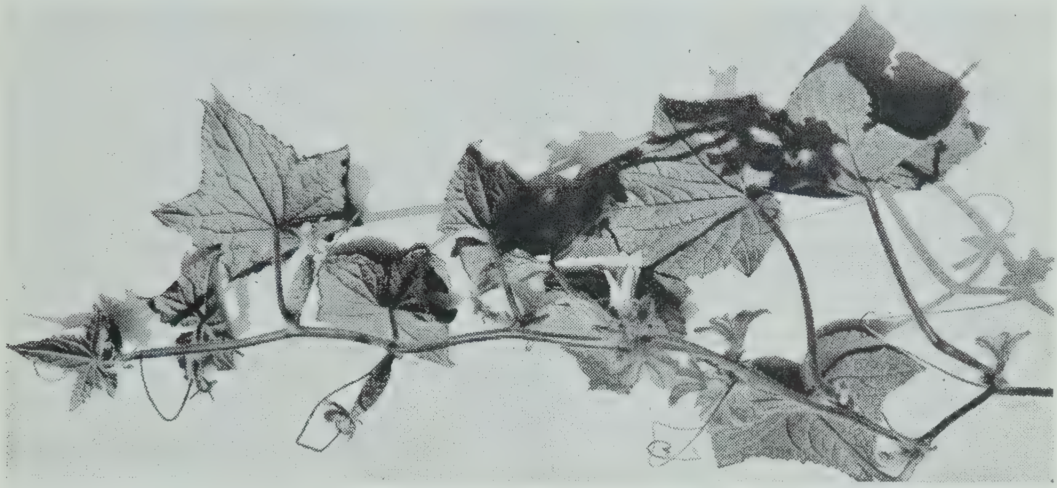


Fig. 87. A portion of a cucumber vine showing its habit of forming flowers at every node. Note that pistillate flowers are formed at only a part of the nodes.

IRREGULAR OR ALTERNATE FLOWERING AND FRUITING

In sharp contrast with the uniform, regular production of flower buds and flowers at every node of some annuals, as the cucumber, and every year in some perennials, as the strawberry and rose, is intermittent, irregular flowering, fruit, and seed production in many other plants. Oaks, pines, spruces, hemlocks, beeches, hickories, and many other forest trees and shrubs may produce a heavy crop of seed one year and then fail to flower and seed for two or three, or perhaps five or six, years, depending largely on environmental conditions. The interval between two periods of flowering may be two years at one time and six years for the same tree next time, while an adjoining tree may be flowering and bearing seed at one- and three-year intervals, or a whole group of trees may be flowering and bearing in unison but at irregular intervals. A similar irregularity in flower bud, flower, and fruit production is exhibited by the fruit trees in many orchards. Some kinds, for example, apples and pears, show a more pronounced tendency to bear alternately than do certain others, for example, cherries and peaches; some varieties, for example, the Baldwin apple, are much more extreme in their alternate bearing tendency than are other varieties of the same kind of fruit. In neglected or poorly cared-for orchards the intervals between flowering are more variable in length and average longer than in orchards that are well cared-for. Some typical spurs from such semibarren, irregularly bearing trees are shown in Figure 88.

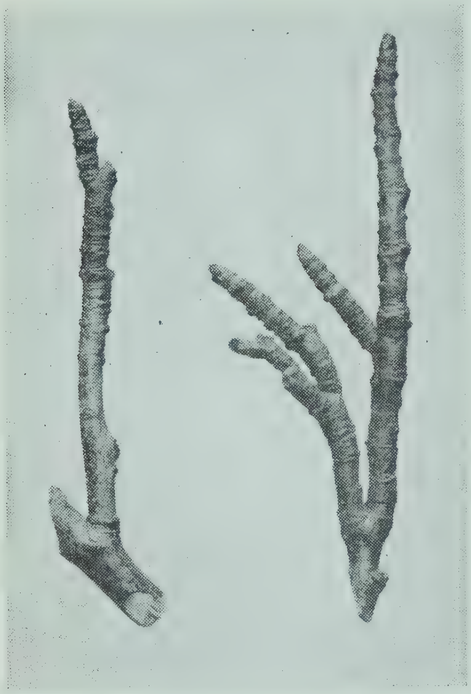


Fig. 88. Old, weak, non-bearing spurs from an apple tree that had been making very little growth. The branched spur on the right was twelve years old when photographed and had produced four flower clusters, but it had never set and matured fruit. Compare with Figure 85.

These differences in regularity of bearing are due more to exhaustion of food reserves, especially carbohydrates, or to an unfavorable carbohydrate-nitrogen balance at the critical period for flower-bud initiation than to basic differences in flowering habit. As a matter of fact, neither terminal nor lateral flowering on either shoots or spurs can in itself be considered a cause for irregular flowering. Both spurs and shoots that produce laterally can make new vegetative growth from their terminal buds, and those that produce terminally can make new vegetative growth from their lateral buds; the new growth, in turn, can differentiate flower buds for the next season's crop, provided nutrient conditions are favorable.

PERPETUAL FLOWERING

Between the condition illustrated by pines, beeches, hickories, and some orchard trees where flowering is at long-separated, irregular intervals and that illustrated by the cucumber where flowers are formed at every node is the intermediate condition shown by great numbers of plants in which flower buds are differentiated with a fair degree of regularity at certain definite, but limited, seasons and likewise definite and limited positions on the plant. To a special form of this intermediate, regular flowering habit is given the term *perpetual*, though in reality the flowering is less perpetual than in such plants as the cucumber. The so-called *perpetual* flowering habit is well illustrated by the common greenhouse carnation (*Dianthus caryophyllus*). A flower bud is formed at the end of its main stem as soon as a reasonable height has been attained, and vegetative growth is checked enough to permit a suitable nutritive condition to develop in its terminal portion. While the terminal flower bud is forming and the flower itself develops, other flower buds (later removed by disbudding in the commercial greenhouse culture of this plant) are being formed at the subterminal nodes, and vegetative shoots are growing out as branches from the more basal nodes. These branches, in turn, differentiate terminal and subterminal flower buds, and this

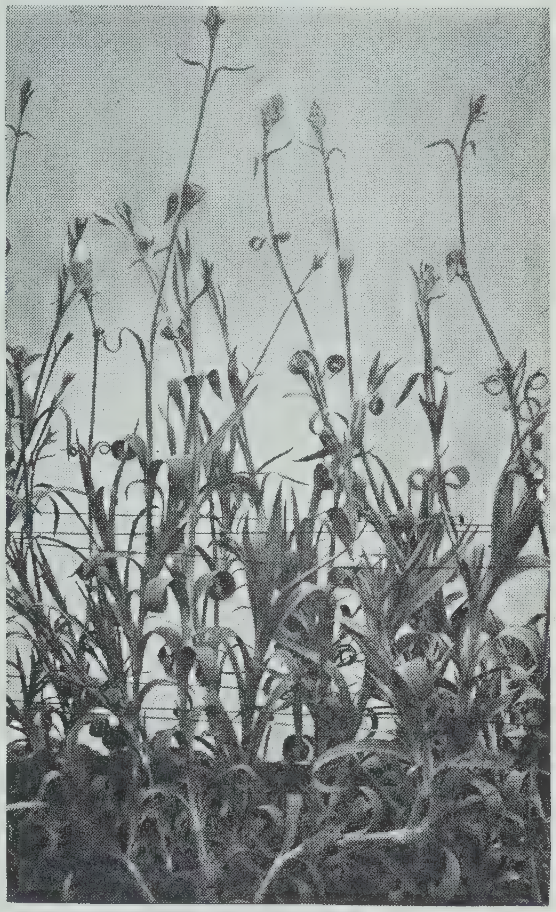


FIG. 89. A section of a greenhouse bench showing a single carnation plant. Attention is called to stems of varying length bearing flower buds in different stages of development. This plant has a "perpetual" flowering habit.

procedure continues throughout the year. At any one time the plant may consist of some branches that have wide open flowers, some that have half-grown flower buds, some that are just differentiating flower buds, and still others that have not yet reached the stage for flower-bud differentiation (see Figure 89). The presence of one stage or type of growth in one branch seems to have little influence on what an adjoining branch does. Each follows and completes its course of development independently, and the plant as a whole is continuously making vegetative growth, differentiating flower buds, flowering, and maturing seed. It has a *perpetual* flowering habit.

More or less comparable growing and flowering habits are shown during the growing season by some of the roses, for example, those belonging to the hybrid tea and hybrid perpetual groups, while in certain other groups, for example, the climbing multifloras, flowering is restricted to a short period in the growing season. The flowering and fruiting habit of the cocoanut palm (*Cocos nucifera*) is intermediate between those of the carnation and the perpetual type of roses, except that its inflorescences are lateral.

FLOWERING AND BEARING HABITS AS RELATED TO PRUNING

Flowering and bearing habit is a plant characteristic controlled largely by inheritance which the grower can do little to change, except perhaps to correct or reduce the irregularity of some kinds that flower and produce only at irregular intervals. Moreover, it makes little difference to him whether flowering is from lateral or from terminal buds, whether flowers and fruits are borne on spurs or on shoots — the important consideration being to obtain the flowers, fruits, and seeds. On the other hand, when he comes to prune his plants, it is very important that he understands thoroughly both their growing and flowering habits and that he is able to recognize flower buds if they are present; otherwise he may remove many of the latter and destroy or injure flower or crop prospects for the coming season. Many flowering trees, shrubs, and vines have their value as ornamentals greatly reduced because the one who prunes them does not realize that he is cutting off many or most of their flower buds or flowering wood. Many orchards come far short of attaining maximum productiveness because of having been pruned with little or no regard to fruiting habit.

PROBLEMS

1. Do you think that vegetative growth slows down because of the initiation of the reproductive processes or that the reproductive processes are initiated because of the slowing down of vegetative growth? Explain why.

2. Does the plant-grower have a greater influence on number of flower buds that may be differentiated by a plant or on the time of year that they are formed, through various cultural treatments and practices at his disposal? Explain.

3. What is the most effective and readily available means at a grower's disposal for influencing the carbohydrate-nitrogen balance in his plants?

4. Would you expect relatively more or less attention necessary to obtaining and then maintaining a certain carbohydrate-nitrogen balance in perpetual flowering or in seasonally flowering plants? Why?

5. Would you expect more irregular flower-bud formation and flower- and fruit-bearing in young than in old trees? Why?

6. Through what factor or factors of environment does "season" register its influence on flower-bud initiation?

7. Compare a random sample of ten four-year old branches from the outside or top of an old apple tree with a random sample of ten from the lower or inside portion of the same tree, from the standpoints of: (*a*) average growth in length per year, (*b*) average diameter, (*c*) number and diameter of spurs, (*d*) average percentage of spurs that have formed flower buds. How do you explain the differences that you find?

8. Make a classification of all the fruits commonly grown in your section from the standpoint of location of flower buds, flowers, and fruits — terminally on spurs, laterally on spurs, terminally on shoots, laterally on shoots.

9. Make a similar classification of at least ten commonly grown deciduous ornamentals.

CHAPTER XIII

TRAINING HORTICULTURAL PLANTS

BY FAR the greater number of cultivated plants is grown without any attempt either to train or prune them, it being assumed either that these plants will attain their best development without any such attention or that any improvement that might be effected would not be sufficient to warrant the effort and expense. Thus, beets and carrots, lettuce and endive, Irish potatoes and sweet potatoes, and most other vegetables, are permitted to grow naturally in the garden; cannas and zinnias, violets and verbenas, peonies and pansies, marigolds and delphiniums, and most other ornamentals, similarly grow as they will; likewise, strawberries and pineapples, cocoanuts and bananas, and many other fruits are produced without any staking, training, trellising, or pruning. On the other hand, other kinds among all these groups are occasionally or regularly trained or pruned and horticultural literature dealing with training and pruning methods is more voluminous than that dealing with any other single phase of plant culture.

TRAINING AND TRELLISING IN ITS SIMPLEST FORM

The training of some plants is effected simply by providing some kind of framework over which they can trail or climb or to which they can cling for mechanical support. There is no artificial tying or fastening. The plant's own tendrils or twisting stems (usually counterclockwise in direction) serve effectively to anchor the main stem and branches. The practices of standing brush along the rows of tall-growing garden peas, of driving stakes in or near the hills of "pole" beans (Figure 90), of planting vines next to a chimney or wall over which they can clamber (Figure 7) are nearly as old as the art of gardening. This training, if such it may be called, does little to *direct* the plant's growth; it is more

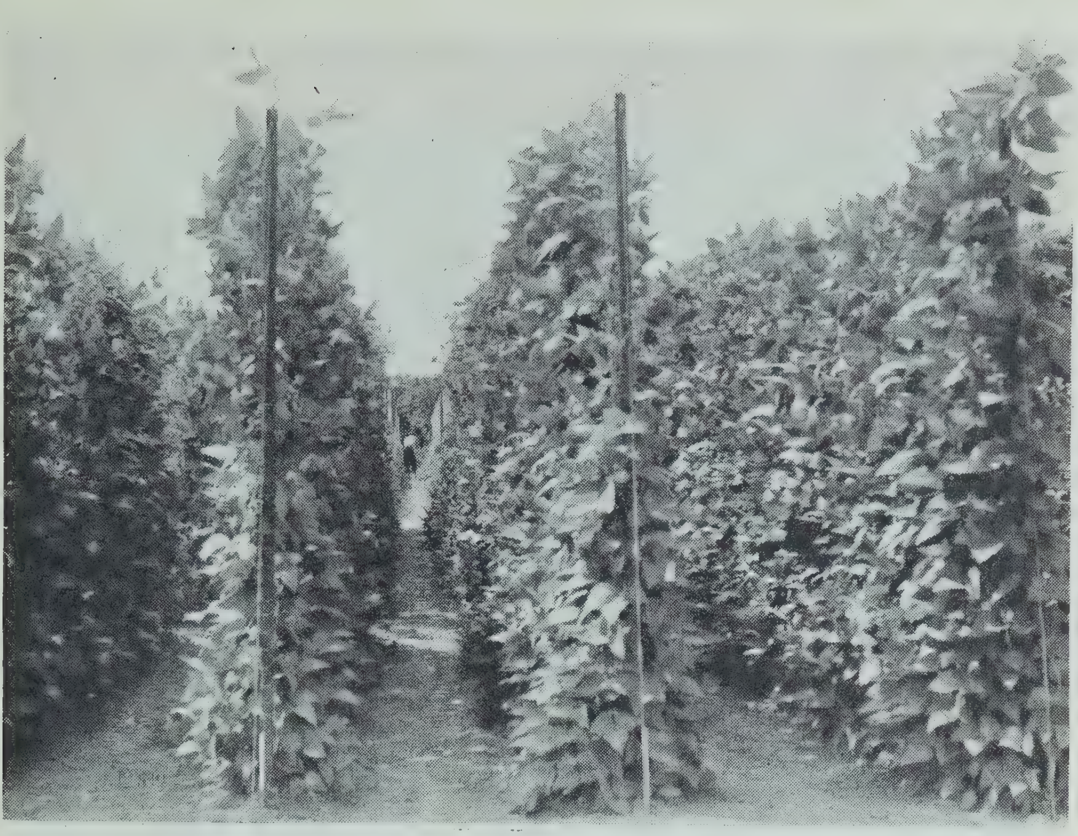


FIG. 90. Pole beans climbing on mesh wire stretched between posts. One of the simplest training methods.

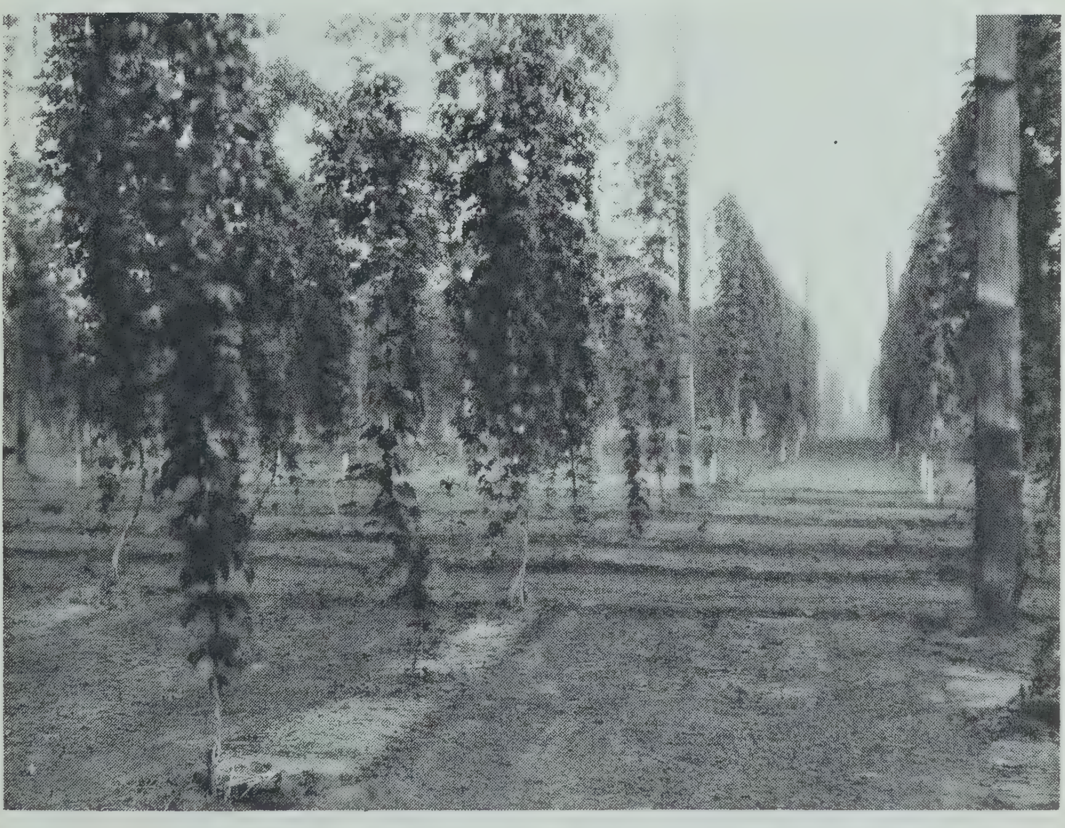


FIG. 91. Hops growing on the vertical and overhead wires of a typical hop-yard trellis. Courtesy of G. R. Hoerner, U. S. Department of Agriculture.

a matter of giving it a chance to grow in a certain place or direction that from man's standpoint suits his fancy or needs better than some other. The combination of posts and overhead lattice of cross-wires in a hopyard (Figure 91) is essentially the same *permissive* system of training, except that the trellis itself is a bit more elaborate and complicated. From simple fences and garden walls on the one hand to balustrades, porticos, pergolas, and arbors (Figure 92) on the other, is a whole series of structures, semihorticultural and semiarchitectural, that serve as mechanical support for numberless species and varieties of ornamental vines in much the same way that brush and poles and wire serve for peas and beans and hops.

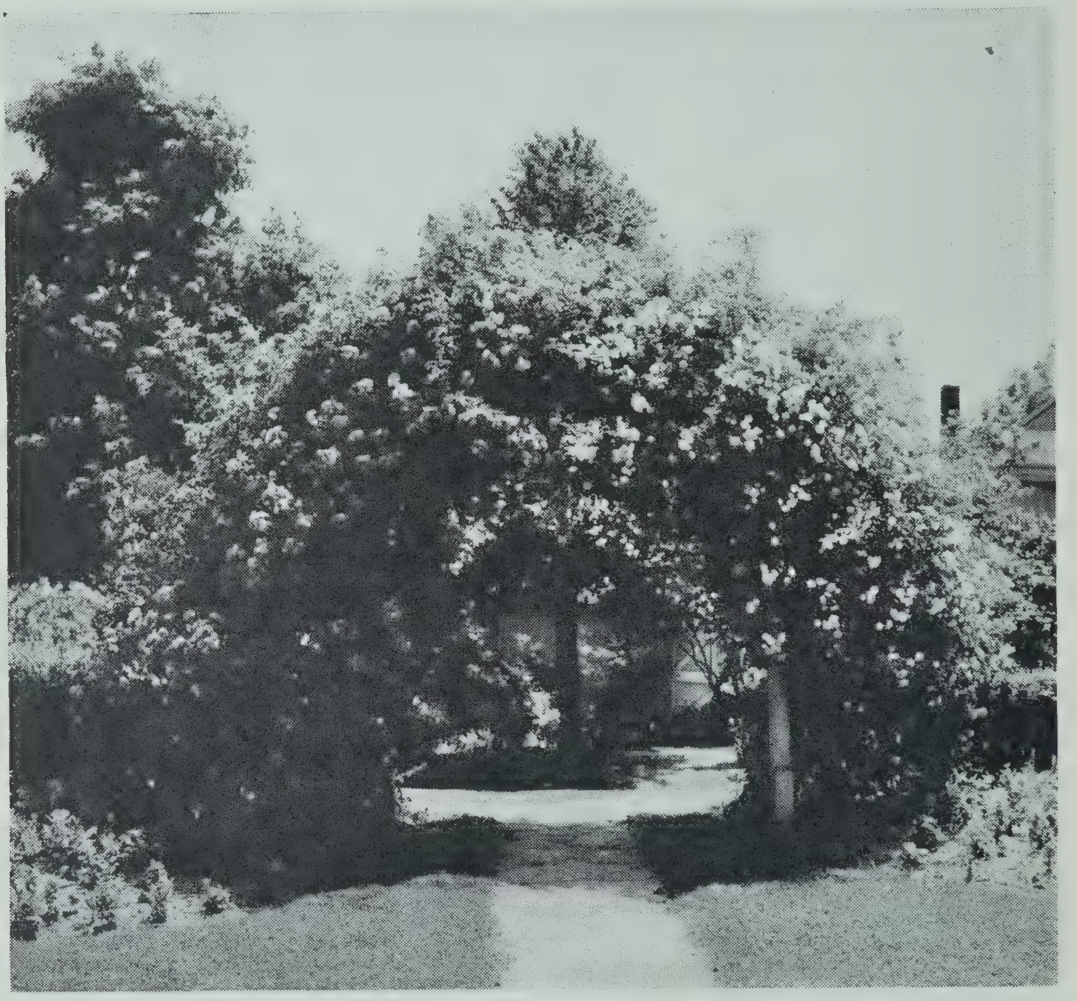


Fig. 92. An arbor at a garden entrance, over which climbing roses have been trained.

From a system or method of training that simply provides a convenient framework over which the plant is permitted to grow more or less at will to one in which the plant or some of its parts are forcibly bent or raised to positions they would not naturally assume and then are artificially tied or fastened in place is but a short step. This is what many an amateur gardener does when he uses frames for his tomatoes (Figure 93) or one of the many wire plant "supports" for his peonies or asters or marigolds; it is what the raspberry-, dewberry-, or loganberry-grower does when he lifts the one-year-old canes off the ground and winds them around stakes or the wires of a trellis (Figure 94); it is what is commonly done with climbing roses.

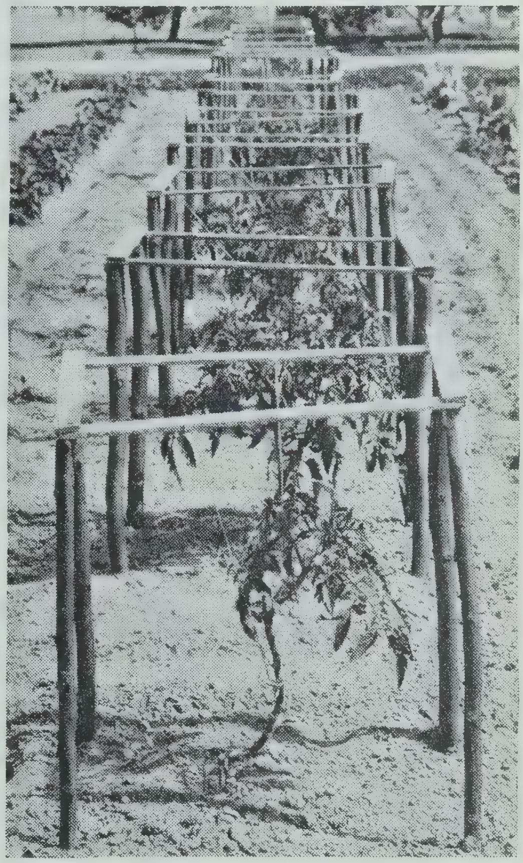


Fig. 93. Stake and slat frames for training tomatoes. They serve to hold the vines off the ground and lessen decay. Courtesy of the U. S. Department of Agriculture.

TRAINING WITH THE AID OF PRUNING

Theoretically, it would be possible, without the removal of any parts, to lift, untangle, and spread out more or less evenly over an arbor or trellis an entire grapevine and then to fasten it in place. In reality, however, this is seldom done because of the amount of labor involved and the fact that the removal of some of the apparently superfluous canes and branches not only makes the task easier but seems in no way to check or harm the vine. Consequently, before any training to some desired shape is attempted, some of the canes and branches are cut away and others are shortened back, the amount of growth removed and the distribution of that which is left being determined largely by the kind of trellis, arbor, or other support to which the vine is to be fastened. This statement applies to the training of many kinds of plants.

The methods of training are as numerous as are the shapes or forms that man desires his cultivated plants to assume. In the case of grapes alone, literally scores of methods or "systems" of training have been employed at one place or another. In the United States today they are commonly trained on two-wire or three-wire trellises in which one wire is directly above another (commonly known as Kniffin systems, if the new shoots are allowed to droop or grow downward), or on two-wire or three-wire trellises in which the wires are on a horizontal plane (commonly known as the Munson systems), or they are tied to stakes or trained as trees (tree or European systems), or amateurs may train them over arbors of various types. A grapevine, trained to the Kniffin system, is shown before and after its spring pruning in Figure 95. There are many other systems, but gradually these three general methods and modifications of them have superseded more elaborate systems because the trellises are less expensive to construct and less labor is required for them. No one system is best for all varieties and conditions. For instance, the Munson or horizontal-wire system is regarded as better than the vertical-wire systems for the more southern sections where shading of the fruit is desirable; the tree system is preferred for the European varieties

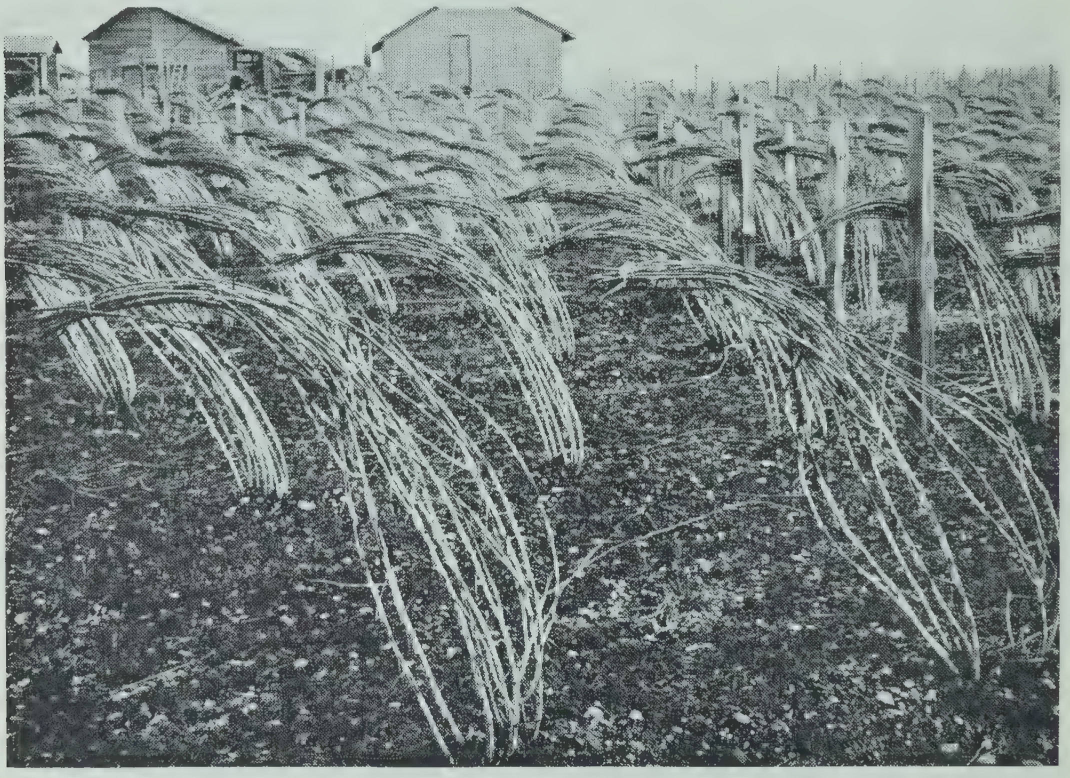


Fig. 94. A method of trellising sometimes employed with black raspberry, Logan blackberry, and dewberry canes.

(*Vitis vinifera*) that make stiff, erect trunks. "Fan" training, using renewal canes that originate at the crown or points on the trunk close to the ground is common in some of the more northern sections where it is necessary to lay the vines down in the fall and cover them during the winter to afford protection from severe cold.

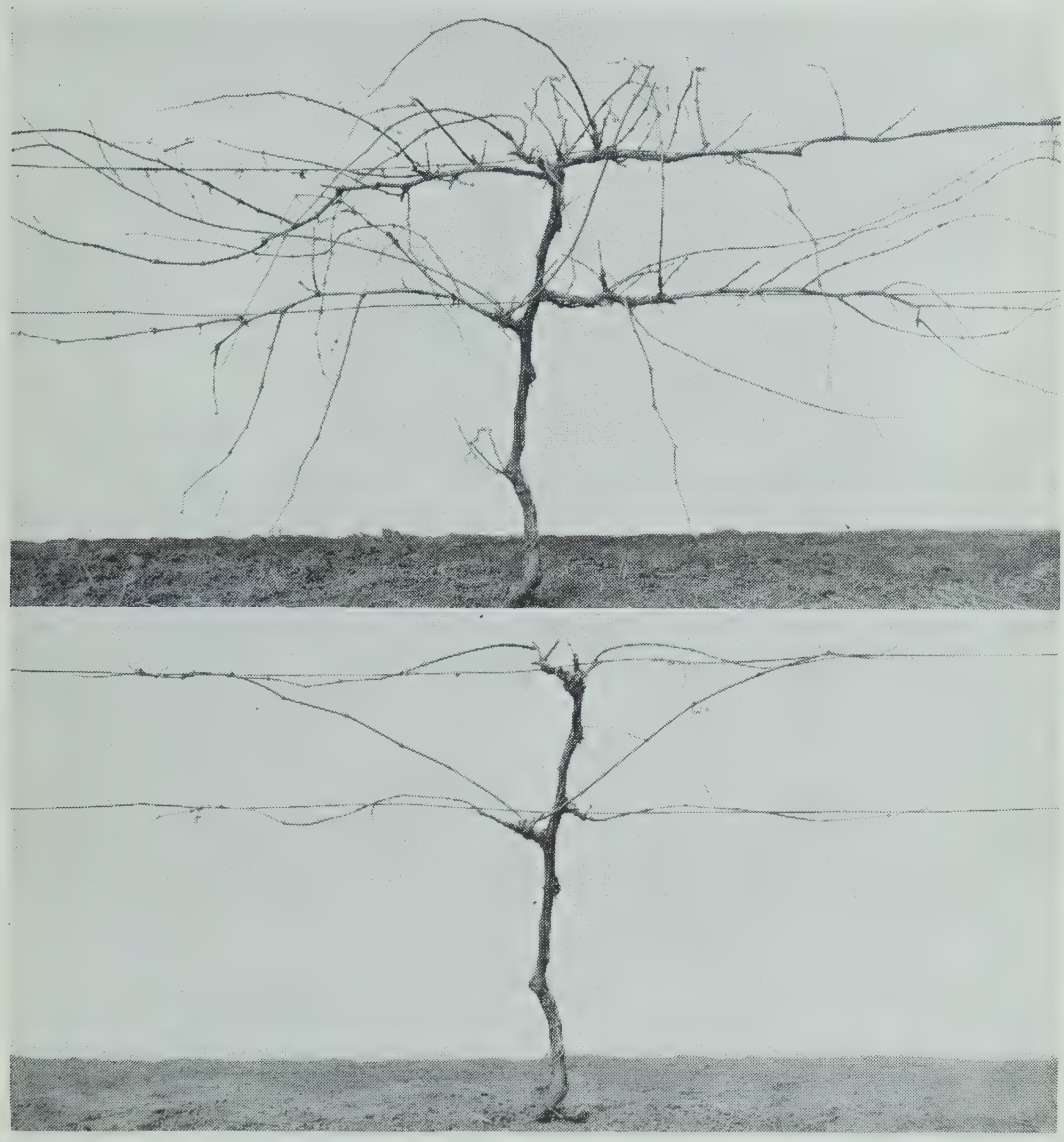


Fig. 95. A *labrusca* type grapevine before and after pruning and trained to the two-wire Kniffin system.

SINGLE-STEM AND MULTIPLE-STEM TRAINING

The training methods that have been briefly described are those used principally with vines, either woody or herbaceous. Trees and shrubs of many kinds, and also some upright-growing herbaceous plants, are likewise trained in various forms, though the methods employed are somewhat different than those used with trailing forms. Less dependence is placed in fastening them in the desired positions and more in restricting or directing their growth by means of removing or cutting back certain branches.

The simplest form of restrictive training consists in removing all side branches, resulting in a "single-stemmed" plant. This is rather commonly employed with tomatoes grown in the greenhouse and also some that are grown in the open (Figure 63), with certain types of greenhouse-grown chrysanthemums and poinsettias, and now and then with many other ornamentals. It obviously rigidly restricts the spread of the plant and permits closer spacing. It entails considerable labor but has the advantage of encouraging the development of especially large, high-grade products — *specimen* flowers in the chrysanthemum. The two- and three-stem systems or styles of training, often used for tomatoes, are but slight modifications of the one-stem system; indeed, the Kniffin, Munson, and other systems of training vines briefly described in a preceding paragraph and illustrated in Figure 95 can likewise be considered as examples of two- or four- or six-stem training. The canes or branches that are retained originate higher on the stem and are made to spread horizontally and are usually called *arms* instead of being fastened vertically to supports, and they are permitted to form laterals.

The many elaborate methods of training apples, pears, and many other fruit trees so commonly employed in Europe a century or more ago and still seen in the gardens of some amateurs, classified as *cordon* and *espalier*, are to be regarded as modifications of the one-, two-, three-, or multiple-stem methods that have just been described. They entail much labor and are entirely impracticable for commercial plantations of the present time. Their principal value is derived from the fact that in sections with cool growing seasons the plants can be spread out fanwise against the south side of buildings and walls where they will receive reflected as well as direct heat from the sun. This has made possible growing many kinds of plants hundreds of miles north of what otherwise would be their normal range.

Though the systems or styles of training commonly employed in the orchards of today are somewhat less extreme, less artificial, than the cordons and espaliers of an earlier generation, some of the names used to designate them — *pyramidal*, *vase-shaped*, *open* *center*, *leader*, *low headed*, *high headed*, etc. — imply that the main difference is one in degree rather than in kind. Such, indeed, is the case. Being simpler in plan or design, they are more readily employed and at much less expenditure of time.

HIGH AND LOW HEADING

In the early days of commercial fruit-growing in this country, and even to the present time with the amateur grower, the orchard has often been used as a pasture. It was generally located fairly close to the farm buildings, and thus was conveniently located from the standpoint of a pasture lot for a few farm animals or as a temporary or overnight paddock for larger numbers. In such orchards the fruits borne by low-hanging branches would be eaten by the animals and the branches themselves were subject to browsing and other mechanical injury. It, therefore, was general custom to prune away the lower limbs so they would not interfere with

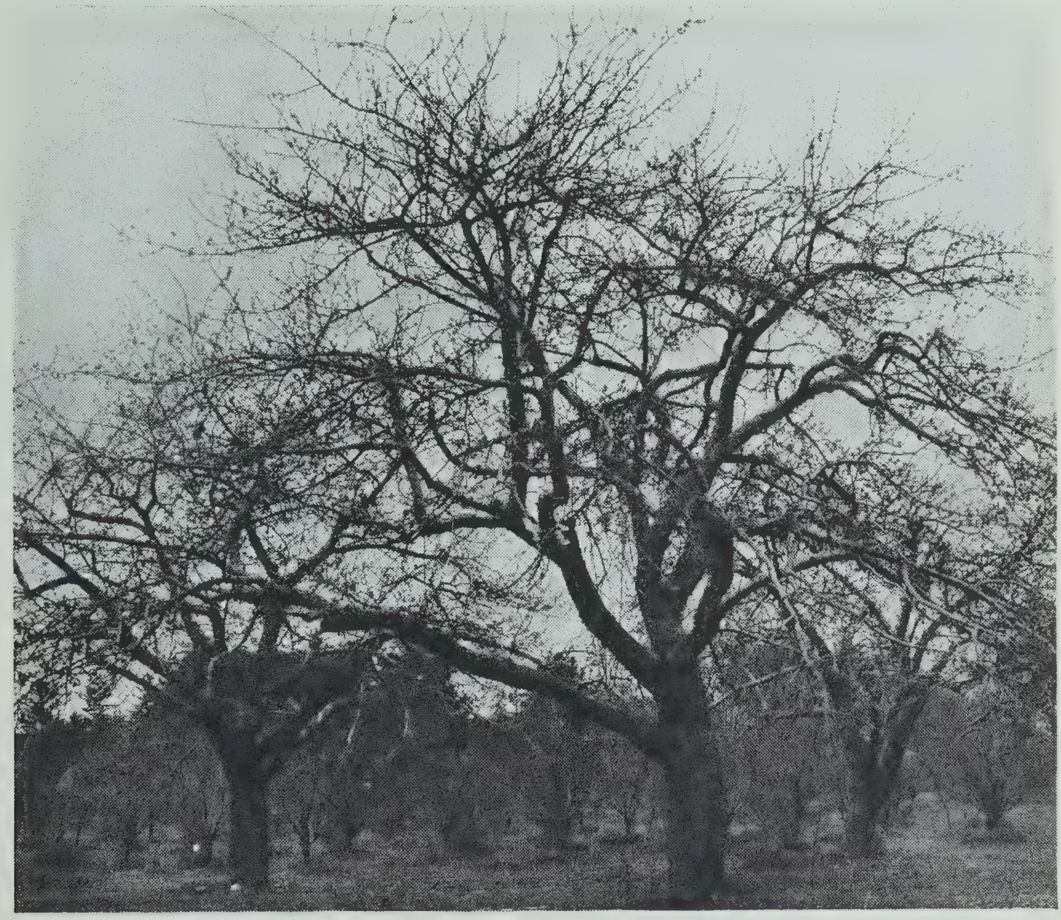


Fig. 96. An old and very high-headed apple tree. Its bearing surface is from eight to twenty-five feet from the ground.

the livestock. The result was high-headed trees, trees with trunks five to seven feet long before the point of origin of side branches, such as are shown in Figure 96. Contrasted with such high-headed trees are those found in most present-day orchards in which there may be a distance of two feet or less between the ground and the lowest branch. These are typically low headed. Ordinarily, the bearing surface of high-headed trees is developed a little later than that of low-headed trees and they are a little slower to come into bearing. As the trees become older, there is a tendency for the bearing surface to become still higher until the condition shown in Figure 96 is reached. Consequently spraying is more expensive and such operations as thinning and harvesting more laborious than in the case of low-headed trees, though Figure 97 shows that by properly pruning back their tops it is possible to keep their bearing surfaces fairly low. High-headed trees are perhaps more subject to wind injury. On the other hand, they are more easily cultivated. Some kinds of trees, peach, for example, are rather difficult to train to high heads; consequently, most of those that we see are low headed.

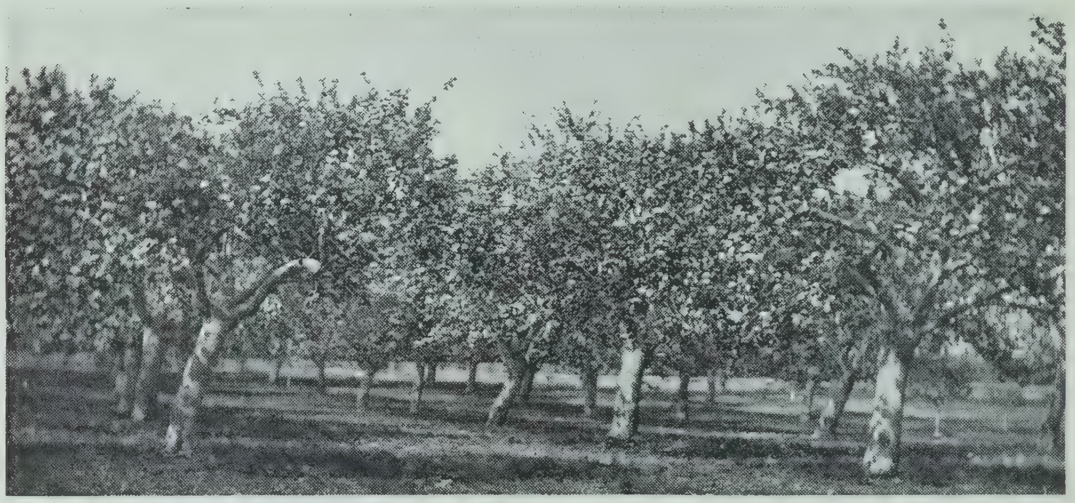


FIG. 97. Old apple trees that, in spite of high heading, have had their bearing surfaces kept low by suitable training. Compare with Figure 96.

OPEN CENTER AND LEADER TRAINING

Both the low-headed tree and the high-headed tree may be trained to the closed-center or the open-center type or style. The main difference between these two systems is in the fact that in the closed-center or leader tree, the trunk or central axis, regardless of where its lowest branches originate, is not cut off or headed back but continues on indefinitely, or if cut back, it is headed less severely than the side branches; the result is more or less of an excurrent type of growth. Figure 98 shows a young tree after its first season's growth following planting before and after pruning to develop an open center and the same tree several months later. Figure 99 similarly illustrates the beginning of a closed-center or leader tree. Figure 100 shows a pear tree after three years' growth in the orchard, before and after pruning to develop a leader type of tree, and Figures 101 and 102 show trees of bearing age trained to open and closed centers, respectively. The central axis or main stem or trunk is thus the dominant feature of the leader tree's framework, even though there may be many branches. On the other hand, in the open-centered tree, the trunk or stem is definitely terminated at the desired point, and all the subsequent growth must be made by its branches. This leaves the center more or less open, though it may be partially filled by growth from the surrounding laterals. Ordinarily, there is only a relatively small number (three to six) of main branches, and these originate from points rather close together (see Figure 101).

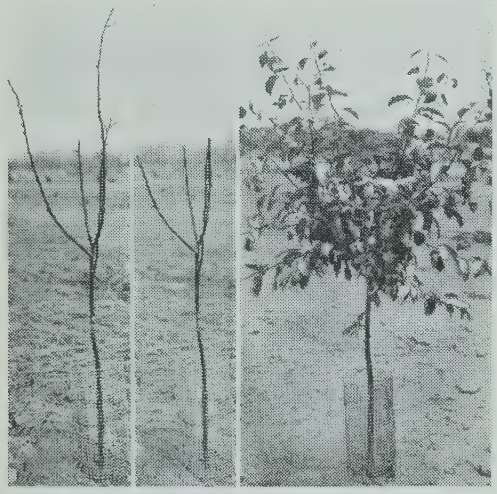


Fig. 98. At the left a one-year-old apple tree before pruning; in the center the same tree after pruning to develop an open-center type of tree; on the right the same tree several months later. Compare with Figure 99.

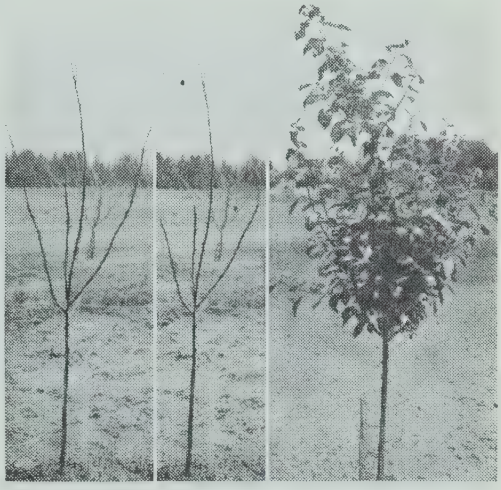


Fig. 99. At the left a one-year-old apple tree before pruning; in the center the same tree after pruning to develop a leader type of tree; on the right the same tree several months later. Compare with Figure 98.

The general tendency of open-center, or vase-shaped, training is to encourage a somewhat more spreading top than does the closed-center or leader tree. Theoretically, at least, this results in a lower head in which the bulk of the crop is borne closer to the ground than in the leader type of tree, thus facilitating spraying, thinning, and harvesting operations. On the other hand, the open-centered tree is more likely to have weak crotches than the leader tree and to be mechanically inferior to it. The natural growing habit of some fruits, for example, most peaches, some of the Japanese plums, and some varieties of apples is such that they are easily trained to the vase form, and it is extremely difficult to train them to the closed-center form. On the other hand, the growing habit of others, for example, most pears, is such that leader-type trees are readily formed while open-center trees can be produced only with considerable difficulty. Rather than trying to train all his trees to a single style, the wise fruit-grower will employ several styles, selecting those that are easily adapted to the growing habits of the varieties that he is producing, for no one system is *a priori* better than all others. Intermediate between the open-center and the leader styles of training is one which is known as the *modified* leader. It embraces most of the supposed advantages of the two more extreme styles and has been steadily gaining in favor.

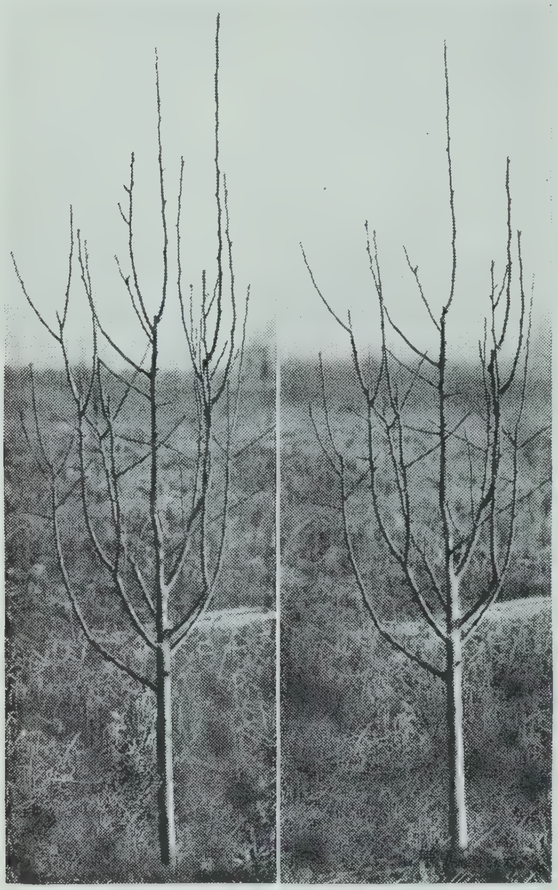


Fig. 100. On the left a three-year-old pear tree, before pruning, that is being trained to the leader type; on the right the same tree, after pruning.

TRAINING TO DIFFERENT FORMS

In the development of orchard trees less attention is now given than formerly to training them to assume some predetermined and more or less artificial shape, such as globose, ovate, flat-topped, conical, pyramidal, etc. This is not so much because the shapes in question do not appeal to the owner as much as they once did, but rather because experience has taught that seldom is a particular shape associated with larger plant size, greater productivity, higher grade of product, or other characteristics that have a greater monetary value. Therefore their extra cost is not warranted by any probable financial return. Now and then, however, one sees a fruit plantation in which the trees or bushes are uniformly trained to a single style, even though it may contain several varieties of markedly different natural growth habits. Such uniform training may be very attractive to the eye, but it seldom yields dividends on the extra maintenance costs.

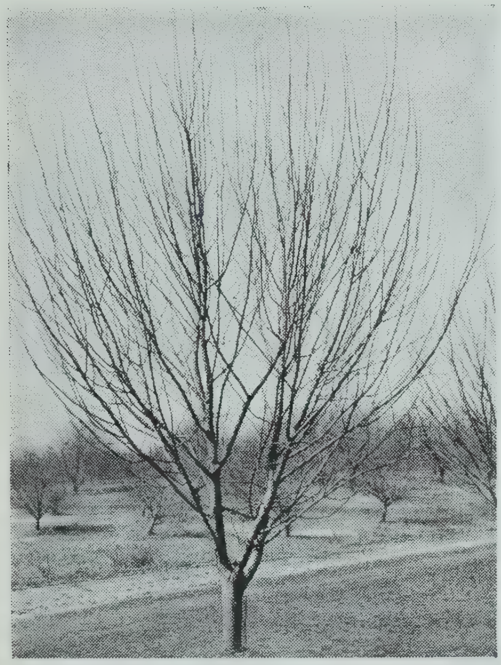


FIG. 101. A Northern Spy apple tree of bearing age that has been trained to an open center. Compare with Figure 102.

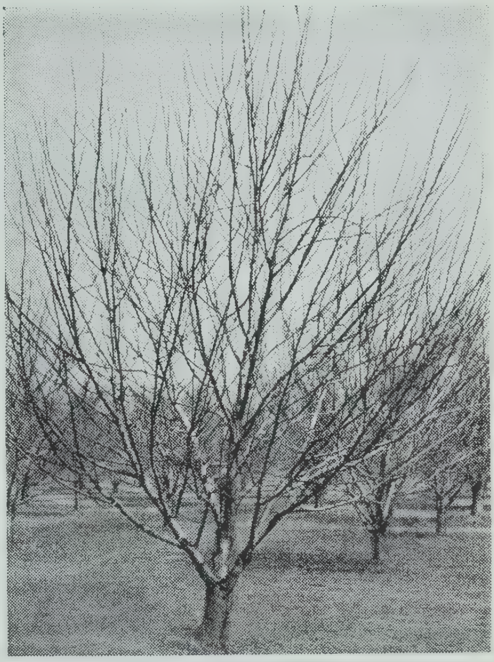


FIG. 102. A Northern Spy apple tree of bearing age that has been trained to the leader type. Compare with Figure 101.

This leads to a discussion of the training of certain ornamentals which are grown in certain locations fully as much for what may be termed their architectural features as for their form, color, and texture as living plants and in which labor and cost of training are subordinate to the effect that is obtained. In most formal gardens symmetry of line and shape is regarded as a necessity. This can usually be obtained with plants only by considerable training and not infrequently to some shape entirely different than that which would naturally be assumed by the plant is desired. Thus, we have everything from comparatively simple geometrical designs (see Figure 103) to elaborate imitations of buildings, birds, animals, and other bizarre figures in the so-called *topiary* gardens (Figure 104). Such forms are obtained by repeated trimming, permitting development only to certain points in certain directions and forcing development in others. The plant may or may not thrive under the treatment, but that is a secondary matter; the main thing is that it survives and retains as long as possible the shape it has been compelled to assume by trimming. The expense of training in formal gardens can often be greatly reduced from what otherwise it might be, by choosing with care the species and varieties that are set in various places and which are supposed to make certain contributions of mass and line. The diversity of present-day horticultural varieties is such that one kind can often be found which, without much training, will attain about the size and assume something of the shape that is desired.

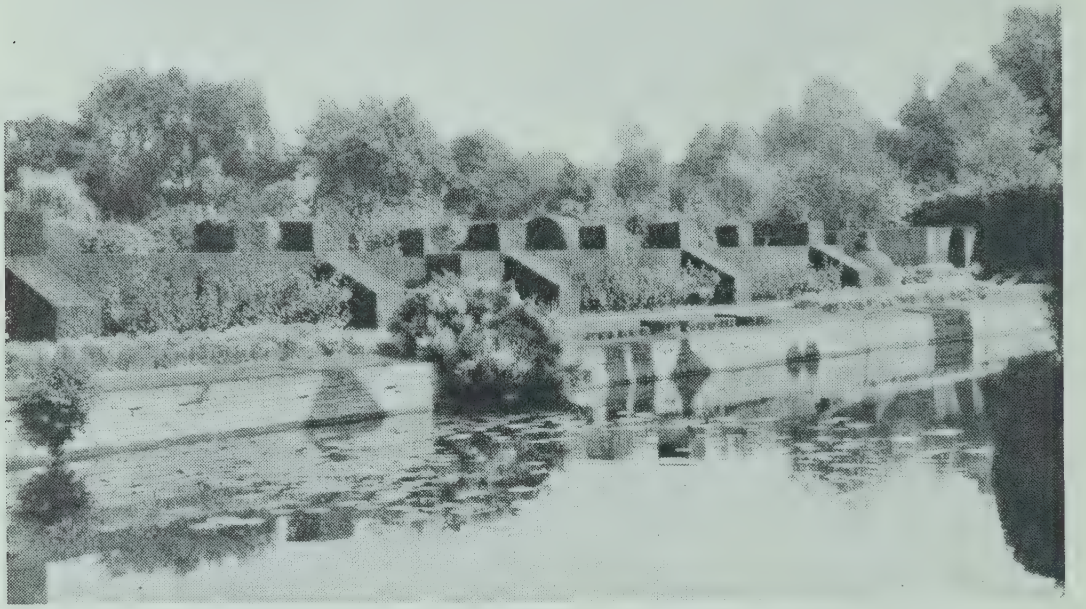


FIG. 103. A battlemented hedge of English yew (*Taxus baccata*) in southern England. Note the geometrical lines obtained by careful training. Courtesy of A. L. Peck, Oregon Agricultural College.

SUBORDINATION OF PARTS IN TRAINING

As has been explained, much training is effected simply by staking, tying, and fastening, no parts being removed by knife, shears, or saw. In other cases, however, training is most easily effected by removing certain shoots, canes, arms, or branches, saving only those parts of the plant that grow or can readily be made to grow where they are wanted. Long experience has resulted in the accumulation of much information about the advantages and disadvantages of different methods or procedures in the training of plants of different kinds. Such details of technique have no place in a book of this kind. There are, however, several growth characteristics of most plants that it is well to bear in mind in all training operations that may be briefly mentioned:

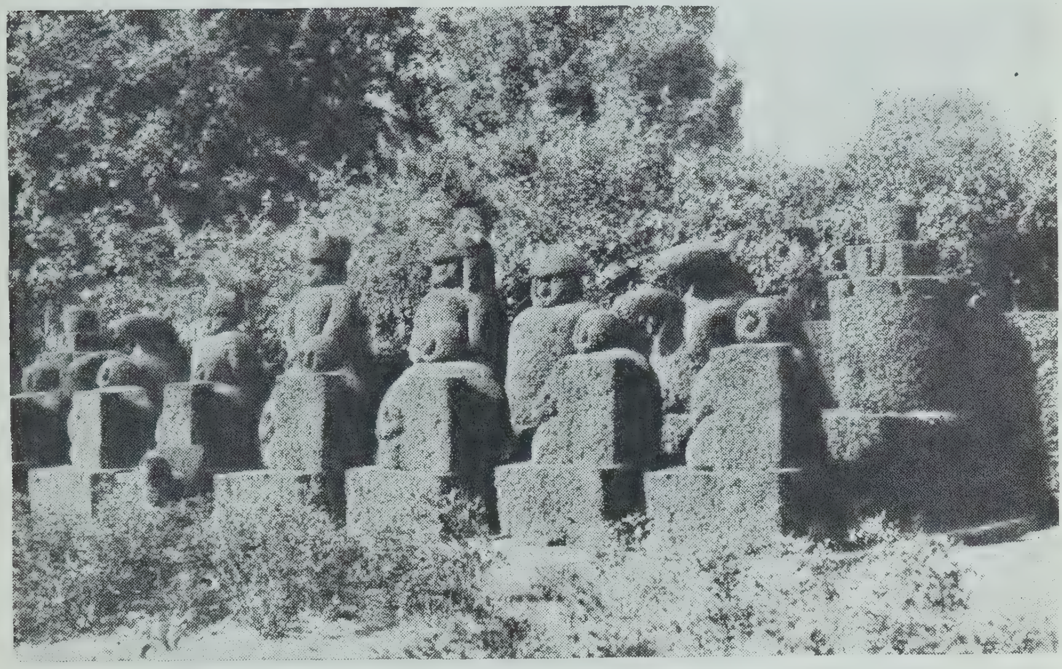


Fig. 104. Topiary training of English yew (*Taxus baccata*) in southern England. The figures are supposed to represent chess men. Courtesy of A. L. Peck, Oregon Agricultural College.

(1) Of two or more shoots, canes, or branches of about the same size and growing in the same general direction, in any one plant, accumulated growth at the end of several seasons will be more or less inversely proportional to the degree or severity of cutting back. There may be little difference in the amount of new growth produced by the two, but the heavier pruned branch will have the handicap of having to catch up with the one pruned less severely. That is, if one branch is left unpruned while the others are headed back, the relative importance of the latter will be subordinated, and their subordination will be in more or less proportion to the severity of their cutting back. Much use can be made

of this principle in subordinating certain parts of the plant or in encouraging one part to outgrow others. This is well illustrated in Figure 105, showing the subordination of the growth from one of the two cions of a cleft graft in a top-grafted apple limb. Failure to make use of it in the early years of a tree's training may result in the formation of bad crotches that will give trouble from splitting in later years. An interesting illustration of the subordination of the leader through failure to prune back the lateral branches arising below it and finally surrounding it and choking it out is shown in Figure 106.

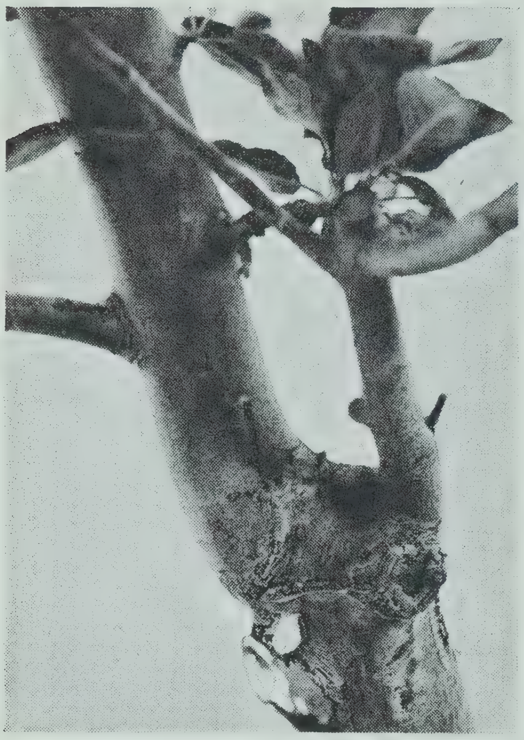


Fig. 105. One of two cions in a top grafted limb that has been subordinated to the other by repeated heavy pruning.

(2) In both trees and vines (less noticeable in shrubs) the strongest growth is very likely to be made from the uppermost buds — uppermost in the sense of being the highest *after* training. Thus, a horizontally tied grape cane will give rise to fruiting shoots of fairly uniform size, while one that is so fastened to the trellis that one part is several inches higher than the other will produce shoots of markedly different size and fruiting capacity. Weak portions of the top can be strengthened, and overvigorous portions can be subordinated, and a balance established between them by proper training.

OBJECTIVES IN TRAINING

From what has been stated it will be seen that training of plants has two main objectives:

1. So to direct the growth of the plant that various cultural operations, as spraying and harvesting, are more readily performed. Thus peas are grown on brush supports; beans are grown on poles; and hops on a wire trellis. Incidentally, both fruit and foliage are kept off the ground, and decay is more or less checked, so some-

thing is gained besides a saving in labor, but primarily training is for the purpose of saving labor. Protection of grapes from insect and fungus attack would be almost impossible without training.

Generally speaking, however, there is less training of both vegetable and fruit plants with each passing decade. This is because most training, unlike cultivation, fertilization, and spraying, calls for considerable hand labor and is consequently relatively expensive. It is for this reason that cordon and espalier training of fruit trees has practically disappeared. Only the simplest, least expensive, training methods are employed today.

2. So to influence the plant's shape that it is more pleasing to the eye and better serves its purpose as a feature of the landscape. For the most part, this type of training is likewise time-consuming and costly. Some of it, for example, the topiary training shown in Figure 104, is very costly, but the results obtained cannot be measured by the same standards as are applied to those attending the training of fruit and vegetable crops; hence less thought is given to cost. If the trained plants are sufficiently attractive, the cost is warranted.

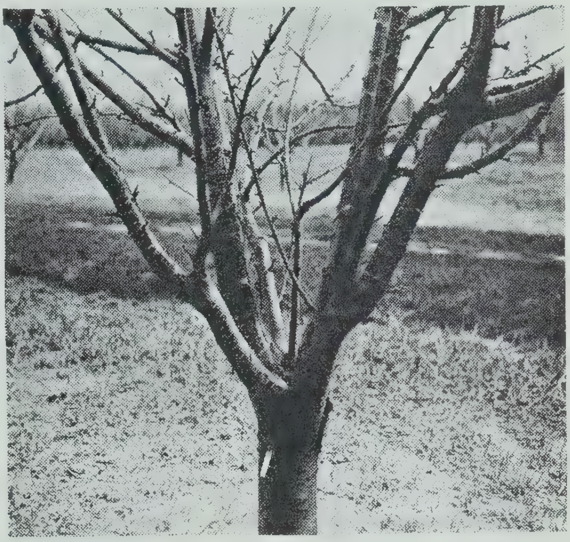


Fig. 106. This sweet-cherry tree was started as a leader tree but the side branches were not pruned back and subordinated to it. The central leader has been "girdled out," resulting in a tree with an open center.

PROBLEMS

1. How, if at all, would you expect the training of a maple tree grown for ornamental purposes to differ from that afforded an apple or peach tree grown for its fruit?

2. Would you think the improvements that have been made in spraying equipment during recent years would complicate or simplify the problem of training of orchard trees? Why?

3. There is often considerable difference in cost between what is regarded as good cultivation and poor cultivation, between good and poor spraying. Would you expect to find relatively less or relatively

more difference in the cost between good and poor training of dewberries? Of grapes? Of a box hedge? Explain why.

4. How does the training of a peach orchard when it is young (before reaching bearing age) compare in amount and annual cost with that required in later years? Make the same comparison for grapes. For a privet hedge. For English ivy covering a wall. Explain the differences.

5. To what extent and in what ways are the objectives realized from training tomatoes on stakes identical with those realized by training apple trees to high heads? To open centers? To flat tops? To what extent and in what ways are they different?

6. The difference between a poor and an excellent job of training may represent a difference in amount of labor and cost involved, or it may represent a difference in knowledge as to the proper methods to use and skill in using them, or it may represent both. The same statements apply to the fitting of land for planting and to cultivating it afterwards. Are inadequate information and poor technique, as contrasted with insufficient labor and cost, the more likely to be responsible for poor results in training plants or in working the soil about them? Why?

CHAPTER XIV

PRUNING

IN THE preceding discussion of the training of plants it was pointed out that many crop plants are never artificially trained. Training of many of those for which training is considered necessary consists simply in providing mechanical supports for them, over which they may climb and to which they naturally attach themselves or to which they are tied or fastened artificially. In training others, however, it is often expedient to break off or cut away, with knife, shears, or saw, certain parts that seem to be in the way. Strictly, this removal of parts is *pruning*, rather than training. If parts are removed without any attendant or accompanying change in shape, the plant is simply *pruned;* no training is involved. If, incident to or following the removal of parts, the shape or position of what remains or the direction of subsequent growth is changed, the plant has been both *pruned* and *trained*. In view of the fact that in the culture of many plants the removal of parts is not for the purpose of effecting any change in shape or in direction of growth and does not result in any such change and that most pruning is for the purpose of influencing plant function or behavior, in distinction from shape or form, it seems desirable to discuss it as a practice separate from training.

As is true of training, pruning is a practice that is seldom or never employed with many plants. Potatoes, beans, beets, cauliflower, and lettuce, among vegetables, are never pruned; tomatoes sometimes are. Marigolds, stocks, Canterbury bells, and gladioli are not pruned, nor are they trained, except occasionally when grown in the greenhouse. Sweet peas are seldom pruned, though they are usually given some kind of mechanical support (that is, are trained). Street and lawn trees are usually given a limited amount of training when they are young, but later are not trained, and in many cases they are not pruned. Bush honeysuckles (*Lonicera*), spiraeas, lilacs, and mock oranges (*Philadelphus*), as a rule, are neither trained nor pruned when they are young, but are occasionally pruned when older. The removal of suckers from sweet-corn plants and the disbudding of roses and carnations do not change the shape of the plants, but they do effect changes in behavior and are to be classed as special pruning practices.

PRUNING — THE LEAST UNDERSTOOD CULTURAL PRACTICE

Though pruning seems to be one of the oldest of cultural practices and certainly much older than some of them (for example, spraying), it is the least understood of any. In the minds of many people it is something, perhaps the one thing, that must be done to many kinds of plants if they are to thrive. This is evidenced by their desire, or even insistence, that their fruit trees or ornamental shrubs be pruned each spring, even though no further care in the way of cultivation, fertilizing, spraying, or dusting is contemplated for them during the remainder of the year. They don't know just what pruning does to or for their plants, nor what it is expected to do. They simply have a blind belief that it is good for them, that it is necessary, that without it failure is certain. Their ideas as to how severe the pruning should be or how it should be done are hazy.

On the other hand, there are those who do not believe in pruning, who think it will prove harmful. In support of this belief, they cite the fact that no one prunes the trees and shrubs of the forest, and they thrive; that, furthermore, the trees, shrubs, and other plants of the orchard and garden, if left unpruned, grow, flower, and mature fruits and seeds.

Which point of view is right? Doubtless something is to be said on both sides of the question. Careful analysis, coupled with observation, shows that there is nothing mysterious or even unnatural, about pruning and that the results or responses that are obtained may be explained on the basis of a few comparatively simple underlying principles. Recognition of these principles not only leads to a better understanding of the responses obtained but furnishes a reliable guide as to what to do and what not to do in the way of pruning.

PRUNING — A NATURAL OR UNNATURAL PROCESS

In the first place, in defense of the practice, it may be pointed out that some pruning is an entirely natural process. In the unpruned tree or bush of whatever kind in the forest, orchard, garden, or along the roadside, twigs and small limbs and large branches die. A comparison of Figures 107 and 108, showing a sumac (*Rhus copallina*) before and after its dead branches were removed will afford some idea of the amount of this dying out of limbs in woody plants that are both vigorous and healthy. These dead branches dry out, become brittle, and finally break off and fall to the ground. This is self-pruning, unaided by man. No one, not even an advocate of no pruning, would argue that the eventual breaking off of the twigs and limbs that die harms the tree, and, if it is not harmed by their natural fall, it would not be harmed by their having been cut off a day or a week or perhaps a month or even a year earlier. By the same course of reasoning, it may be concluded that removal still earlier, when the twig or branch had become so weakened that its early death could have been predicted, would not have been harmful. Parenthetically, it may be

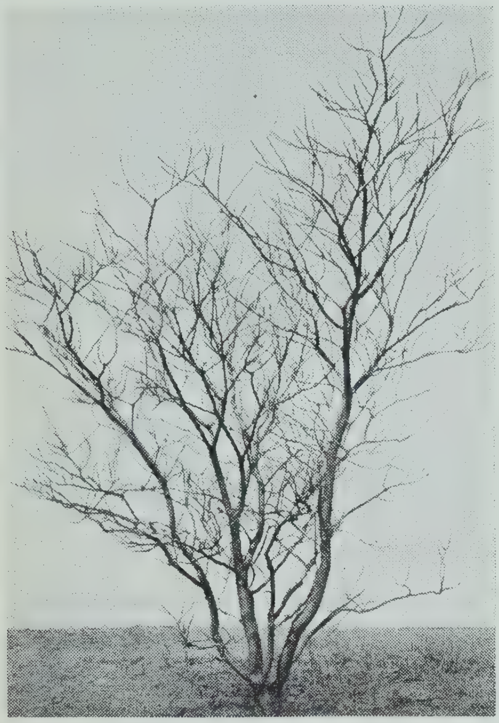


Fig. 107. A fifteen-year-old bush of the shining sumac (*Rhus copallina*) that had not been pruned for several years and that contained much dead wood. Compare with Figure 108, showing the same plant after the dead wood had been pruned out.

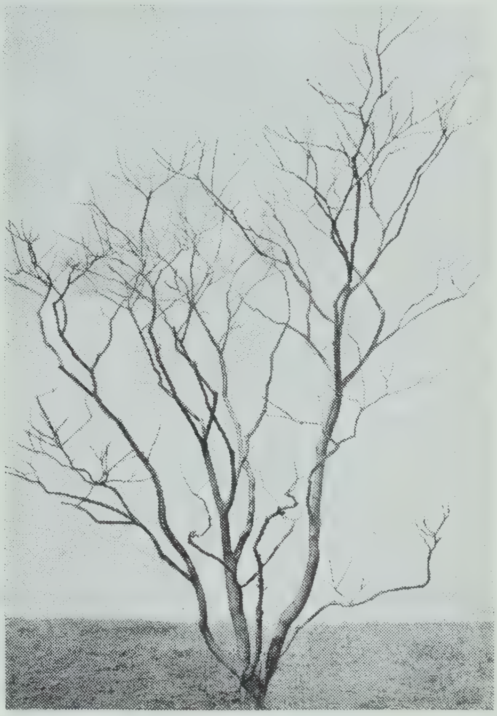


Fig. 108. The shining-sumac (*Rhus copallina*) bush shown in Figure 107, after its dead branches had been pruned out.

remarked that the pruning out of this type of wood, which is of little or no further use to the tree, is the safest and yields the most favorable responses.

PRUNING — A SUBTRACTION PROCESS

Obviously, pruning of any kind whatsoever is a subtraction process. The plant is left with a shorter stem, fewer branches, less leaves, or fewer roots than it had before; furthermore, there is more or less of a corresponding reduction in potential new growth of stem, leaves, branches, and roots that otherwise would be developing from the removed parts. Incident to this removal of vegetative parts, there is a reduction in flower-, fruit-, and seed-bearing surface, if not in flower buds themselves, and there will be a corresponding reduction in the *number* of these organs of reproduction. In brief, the plant as a whole is reduced in size by pruning, and this in turn generally means a slower subsequent increase in size. There is likewise a reduction in present and future productivity, as measured in terms of numbers of flowers, fruits, and seeds. This dwarfing influence is slight or decided, depending on whether the pruning is light or severe and also depending on the number of flower buds it removes. If the pruning is very severe, and continued season after season, it may result in progressive dwarfing of the plant, for the total growth that is subtracted will exceed that which is being added through the formation of new wood, leaves, and roots. The cumulative effect of this process of subtraction for a ten-year period is well illustrated in Figures 109 and 110 of Northern Spy apple trees that each year were pruned lightly and heavily, respectively.

This does not mean that no pruning is warranted or that all pruning should be light. It depends on conditions. While the plant is young and small, and rapid increase in size is wanted, pruning should be relatively light. This is just the opposite of the procedure followed by many, on the erroneous assumption that severe pruning "invigorates" the plant and makes it grow more rapidly. The trees in many an orchard have been dwarfed during their early years and their bearing considerably delayed by too severe pruning, by subtracting each year almost as much wood growth as was produced the preceding season. On the other hand, when fruit or ornamental plants attain about as large a size as it is considered desirable for them to have, pruning should be more severe;

annual subtractions should about equal annual additions. This stage of development is often reached fairly early in the life of a hedge or a rose bush. Seldom is very severe pruning — severe in the sense of annual subtraction in excess of annual increment — warranted with either fruit or ornamental plants. However, it should be noted that the amount of pruning that is severe, in the sense just defined, for one plant, for example, the sweet cherry or rhododendron, might be comparatively light for another, for example, the grape or the Anthony Waterer spiraea.

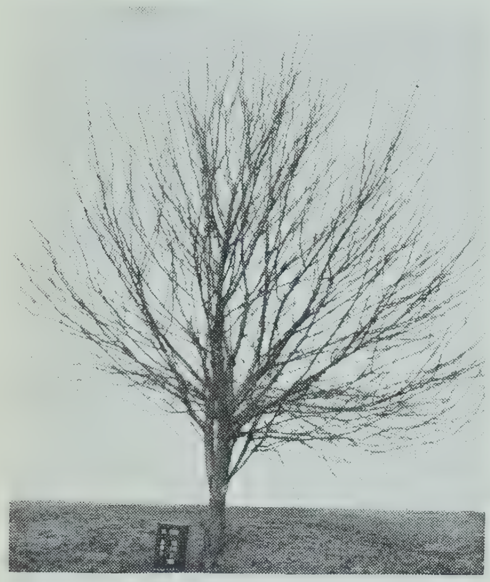


FIG. 109. A 10-year-old Northern Spy apple tree that had received light pruning every year. Compare with Figure 110.

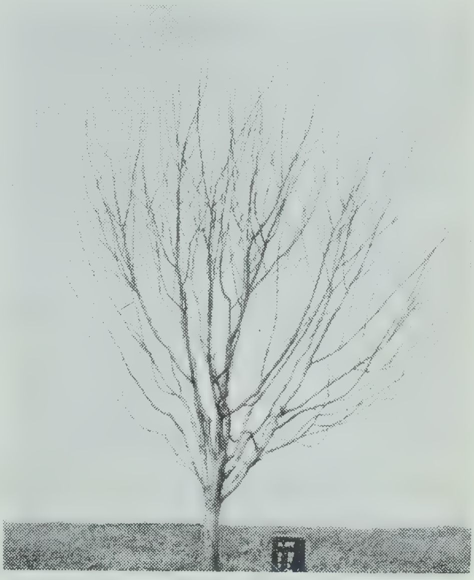


FIG. 110. A ten-year-old Northern Spy apple tree that had been heavily pruned every year. Note the dwarfing effect of the heavy pruning by comparing with the lightly pruned tree shown in Figure 109.

PRUNING — A MEANS OF DIVERTING THE PLANT'S ENERGIES

Removal of a portion of a plant's top (stem, branches, or leaves) temporarily changes the top/root ratio. That is, the same root system exploits the same moisture and nutrient supply in the same soil mass but supplies fewer branches, leaves, and growing points than before. The result is a larger amount for each one, and consequently the possibility of its growing more rapidly than otherwise it would, at least until its supply of carbohydrate becomes a limiting factor. Pruning is thus a means of diverting a portion of the plant's water and nutrient supply from one part or growing point to another, as illustrated by the growth from the two cions shown in Figure 105. Much of the most effective, intelligent pruning is done with this objective in view. A limb or branch or a whole side of a plant that is being outgrown and subordinated by other parts of the plant may be stimulated into more active growth by pruning back the more vigorous members and diverting a portion of their energies into the weaker members. It is in this way that a well-balanced, symmetrical top can be developed and maintained. This function of pruning is of relatively more importance in the culture of ornamentals than of plants grown for their edible leaves, fruits, or seeds.

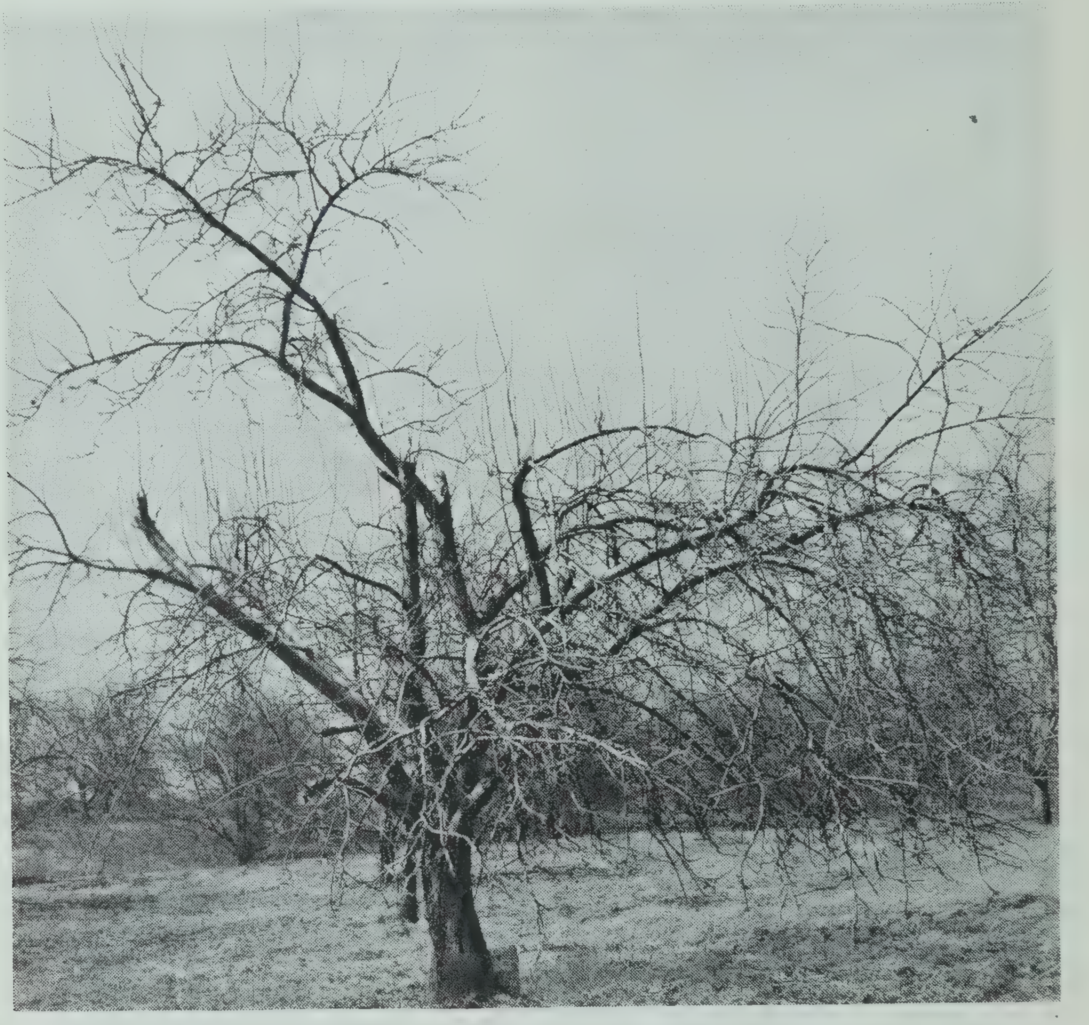


FIG. 111. A recently top-grafted apple tree, showing how the severe cutting back of limbs incident to the grafting operation has resulted in forcing out many watersprouts. Note that these watersprouts spring mainly from the limbs that were pruned back and that the unpruned branches show little response to the pruning.

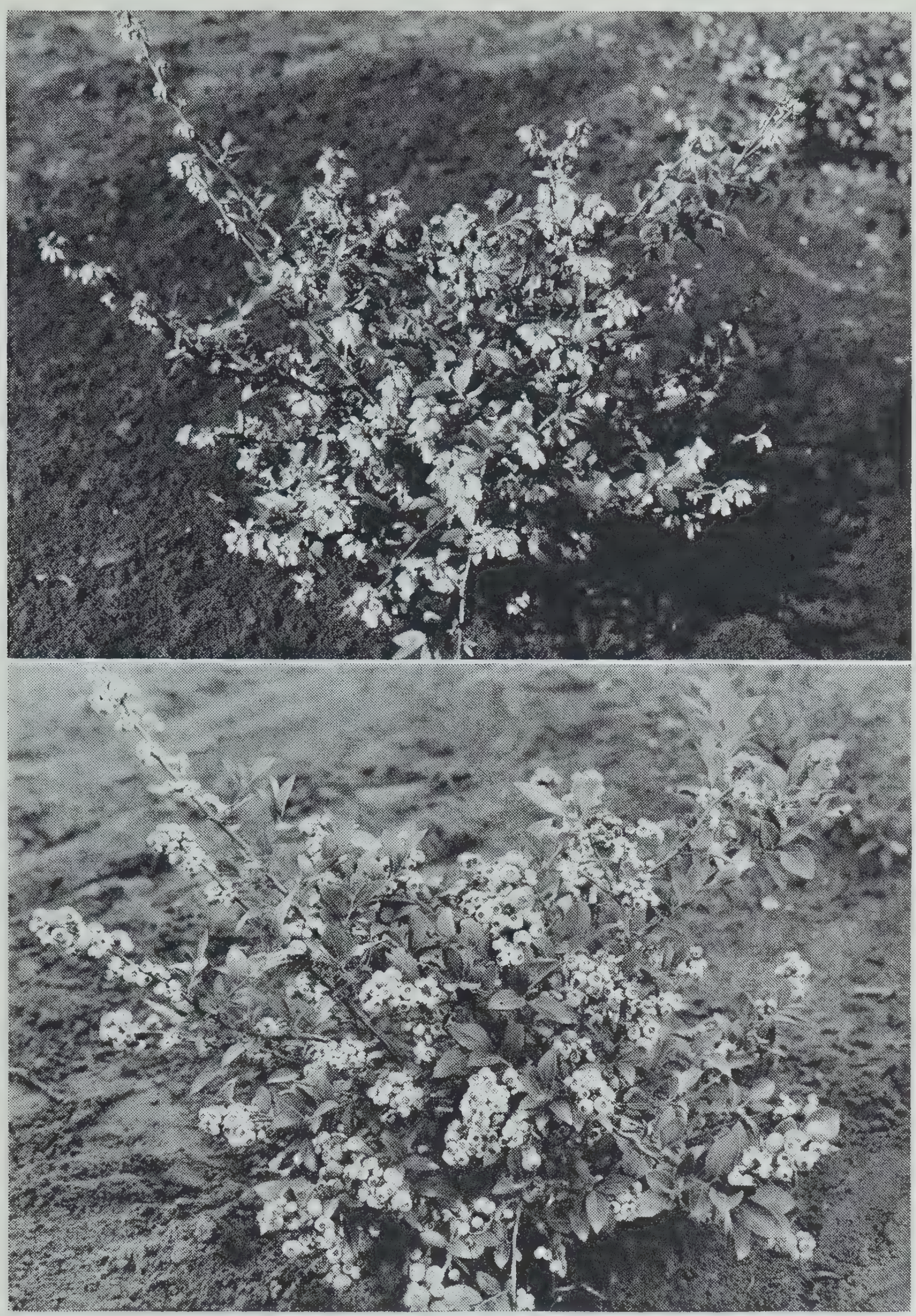


Fig. 112. Above is a photograph of a four-year-old blueberry plant of the Pioneer variety, in full bloom. It was not pruned, nor were its blossoms thinned. Below is a photograph of the same plant two months later. Note its very heavy crop of fruit and the very small amount of new vegetative growth it has made. Compare with Figures 113 and 114.

A special, and usually undesirable, effect of diverting the energies of a plant from one growing point to another is often seen following severe pruning when watersprouts or suckers are forced out

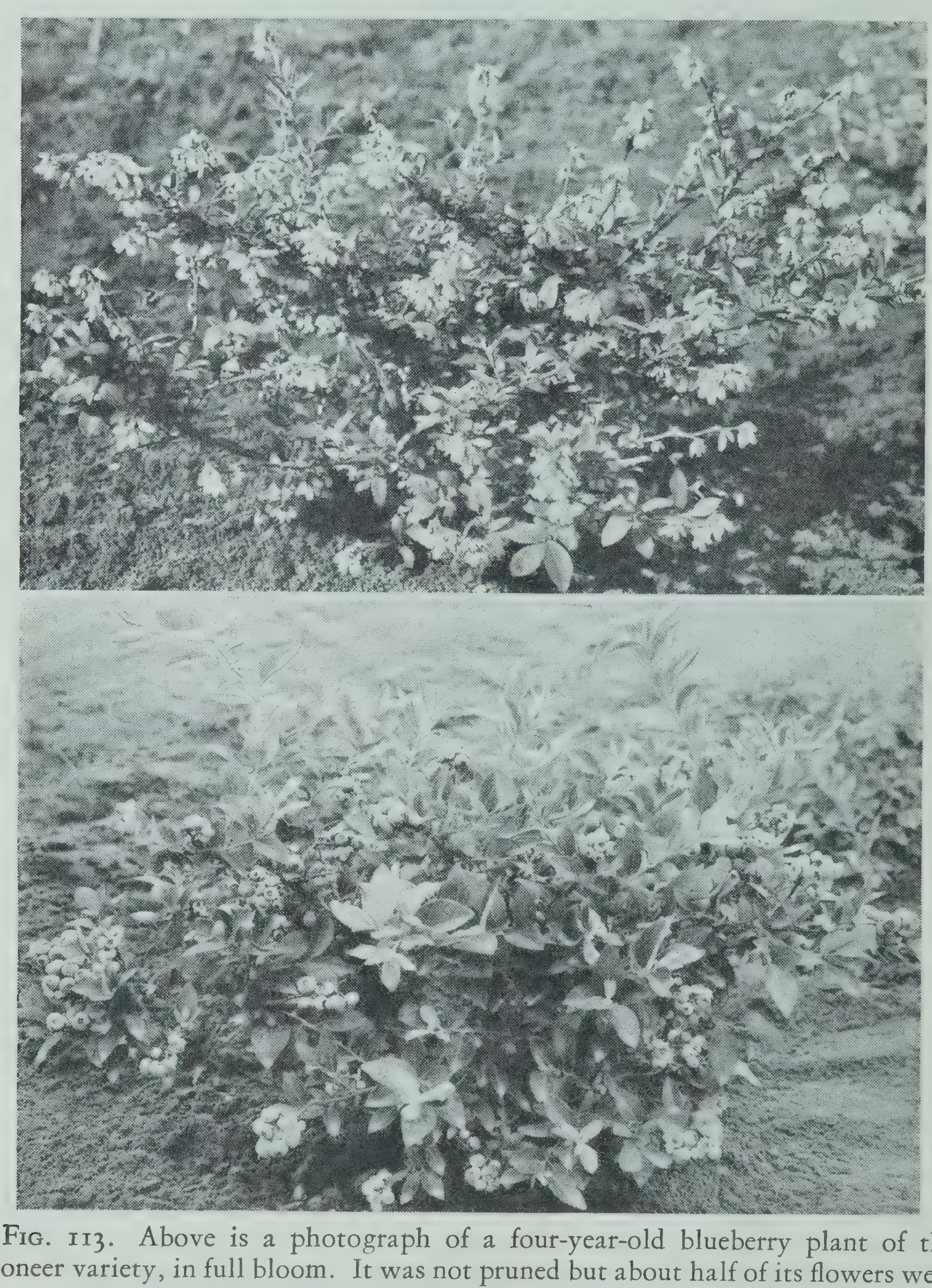


Fig. 113. Above is a photograph of a four-year-old blueberry plant of the Pioneer variety, in full bloom. It was not pruned but about half of its flowers were removed. Below is a photograph of the same plant two months later. Note its set of a moderate crop and at the same time the development of a considerable amount of new shoot growth. Compare with Figures 112 and 114.

from dormant or adventitious buds on wood several years old or perhaps much older, sometimes from large scaffold limbs or even the main trunk or the crown (see Figure 111). These growths are evidence of a balance between top and root that has been badly upset. Sometimes watersprouts can be utilized to advantage in renewing portions of the top and replacing wood that has become weakened from overbearing or other causes, but generally they indicate too heavy pruning and should serve as a warning against its repetition.

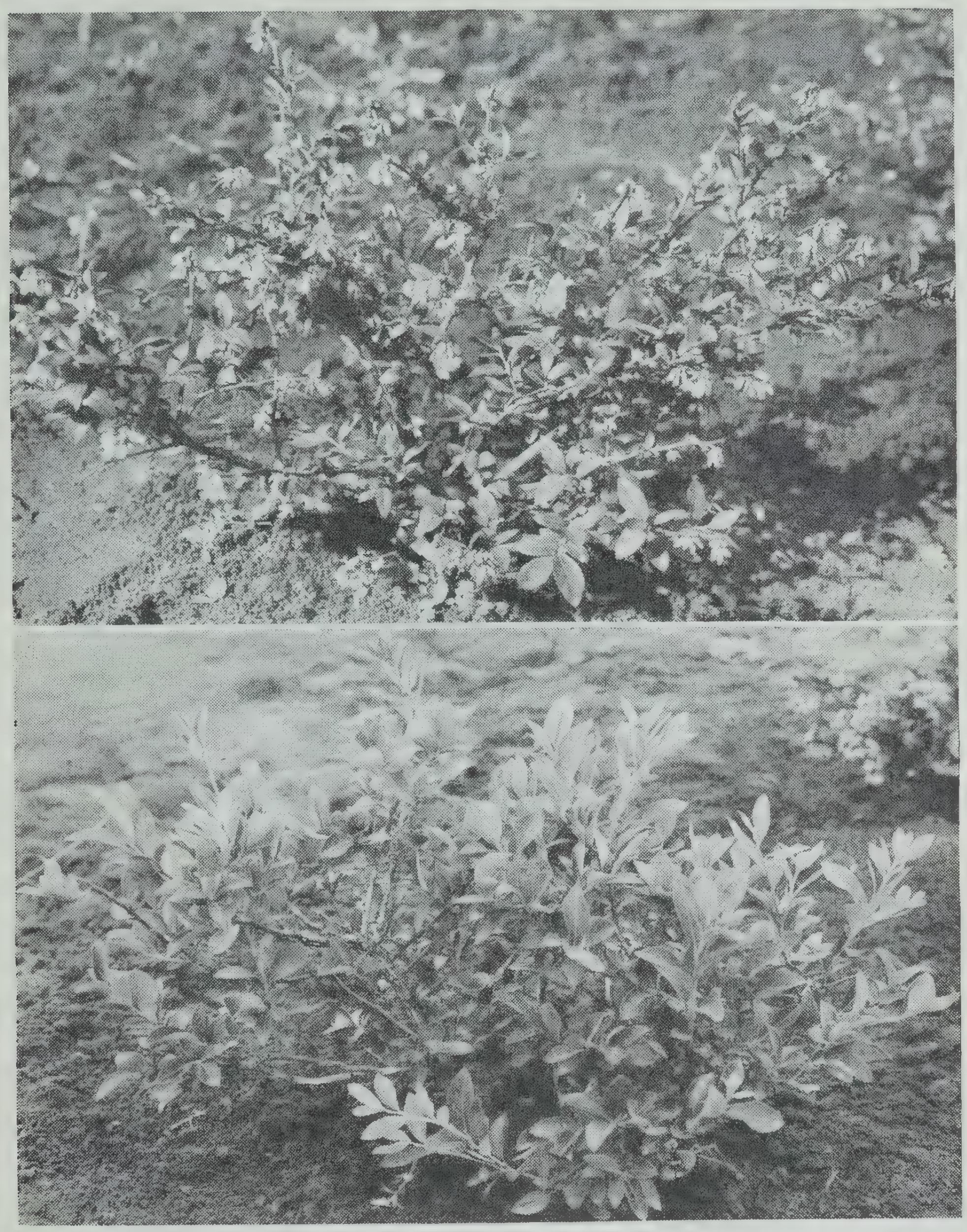


Fig. 114. Above is a photograph of a four-year-old blueberry plant of the Pioneer variety, in full bloom. It was not pruned but practically all of its flowers were removed. Below is a photograph of the same plant two months later. Note its strong new shoot growth, as compared with the plants shown in Figures 112 and 113.

Another illustration of utilizing the diverting influence of pruning is seen in plants that characteristically tend to form far too many flower buds, flowers, fruits, and seeds for their own good. If left to themselves, they "bear themselves to death," as the grower phrases it. This, literally, is what sometimes happens, though more often the plant simply is greatly weakened and dwarfed by the heavy bearing. The Lombard plum, the Harding blueberry, the Victor tomato, the Sheridan grape, the Marie Legraye lilac, are varieties of the fruits, vegetables, or ornamentals in question that show this tendency to a marked degree. More or less severe pruning (or perhaps thinning), especially of a kind that removes flower buds or flowers, diverts a portion of the energies of the plant from reproductive activities to vegetative growth, and the plant as a whole is invigorated. This is well illustrated by the blueberry plants shown in Figures 112, 113, and 114. Thus, it is seen that pruning may have diametrically opposite effects on vegetative vigor and plant size — reducing them, as shown in Figure 110, when vegetative growth principally is removed, and increasing them, as in the case of the blueberry plants, when flower, fruit, and seed production is reduced or prevented.

PRUNING — A MEANS OF FLOWER AND FRUIT THINNING

Many kinds of plants normally and naturally produce flowers in such abundance that, if they are all allowed to develop, few or none have a chance to attain maximum size or a size that is satisfactory from the standpoint of the plant-grower. Cultivation, irrigation, and fertilization are practices commonly employed to improve size and market grade, but with a heavy setting of flowers they have their limitations. Thinning of blossoms or removal of blossom buds (or fruits, if it is a fruit crop), which is in reality a special type of pruning, is a very effective method of dealing with this problem and is commonly practiced in the greenhouse with roses, carnations, chrysanthemums, and a number of other crops. From disbudding to the removal of certain branches so that those which remain can bear larger flowers or fruits is but a short step, and this latter practice is plainly a case of pruning. It may be regarded as prethinning or anticipatory thinning, or it may be considered as another type of diverting the energies of the plant from one point to another, the point or organ of utilization being a flower or fruit. This is by far the most important objective in pruning practice, whether with fruits, such as the peach, plum, grape, and raspberry, or with ornamentals, such as the rose or hibiscus, or with vegetables, such as the tomato and watermelon. The gain in size, grade, and quality serves to compensate for the decrease in numbers occasioned by the *subtracting* effect of the pruning.

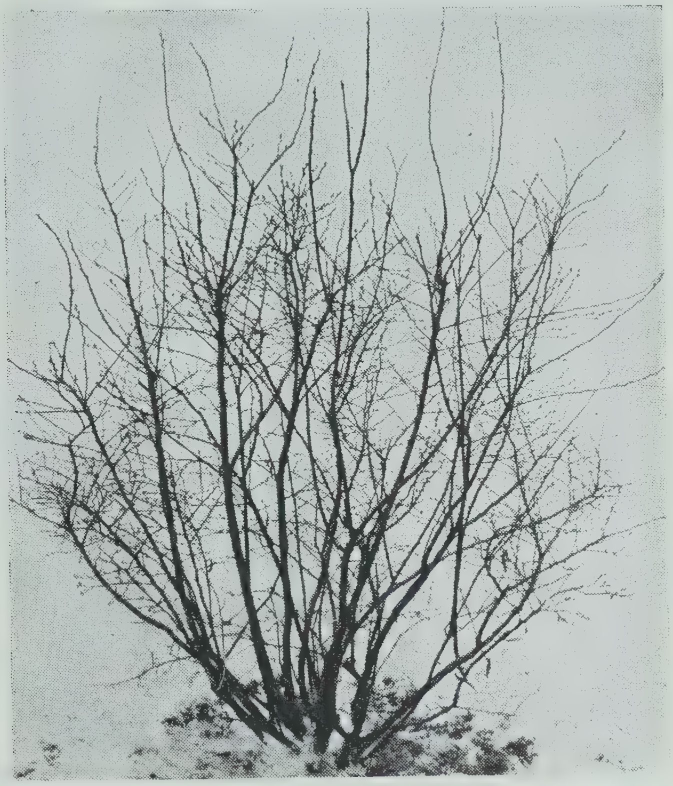


FIG. 115. A high-bush blueberry plant of the Rubel variety, before pruning. Compare with Figure 116.

Observation shows that with many kinds of both fruits and ornamentals the largest and best fruits and flowers are borne on the strongest, most vigorous shoots and spurs (at least within certain rather wide limits), and the smallest, poorest specimens are borne on the weaker wood. This means that the type of pruning that is most effective in increasing size of flowers and fruits and in improving their grade and market value without at the same time causing too great a reduction in their total quantity, is one that removes the thin, weak, slender wood and retains that which is naturally strong, thick, and stocky. This has been aptly designated the *thin-wood* method of pruning, a term that is descriptive as well as designative, and is illustrated in Figures 115 and 116.

A more or less diametrically opposite method of pruning — namely, removal of much of the thick stocky wood in an attempt to invigorate that which is weak — has often been recommended and is still widely employed to attain the same objective. On the whole, it is ineffective for it retains the poor wood whose product is but little improved, while the thin-wood pruning method retains the best wood and effects an equal amount of improvement in its product. Both methods effect some improvement in size and grade of the flowers and fruits that remain after the pruning, but one method improves upon the best while the other improves upon the poorest. Furthermore, removal of the weak wood is seldom followed by the development of watersprouts and suckers, such as commonly attends the removal of stronger wood and larger limbs.

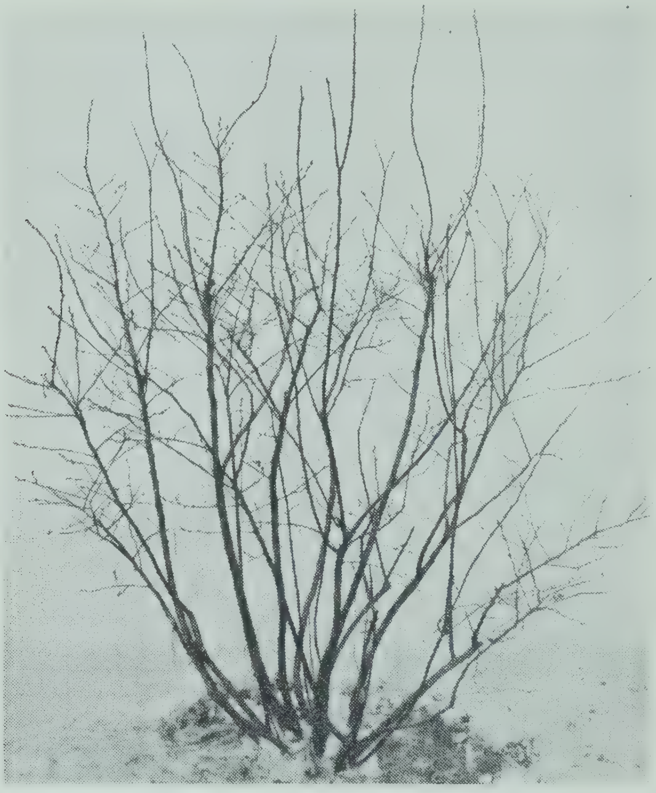


FIG. 116. The blueberry plant shown in Figure 115 after its "thin" wood had been removed by pruning.

THINNING OUT AND HEADING BACK

The response of a plant to pruning depends not only upon its amount or severity but likewise upon the method of removal of parts. One commonly employed method or procedure is to remove entire shoots, branches, or limbs, the cut being made at the point where the shoot, branch, or limb grew out from the parent stem structure. This is a thinning-out process. Another method is to remove only the terminal portion of the shoot, branch, or limb, leaving its basal portion intact. This is heading back. It is possible to prune with equal severity, that is, remove the same amount of wood, with either method. Sometimes the one method is used almost exclusively, sometimes the other, more frequently a combination of the two methods. Which is the best procedure depends on conditions, on the kind of plant, and on the objective in view. In general, heading back tends to restrict the plant's growth in space, to make it less rangy, more dense and compact, an objective that is sought in a hedge and in many ornamentals, particularly those grown for their foliage in borders or for edging and for their symmetry of outline in formal gardens. Compactness of growth is also an objective in pruning certain fruits, such as the peach, which are subject to considerable breakage of limbs and splitting at the crotches if they are permitted to become rangy. Heading back is also commonly employed as a means of subordinating parts and as an aid in training. Thinning out is more commonly employed with fruit-producing plants and with ornamentals that are produced more for their flowers or the color and texture of their foliage rather than their geometrical forms. The general heading back of kinds that produce their flower buds terminally or subterminally on shoots — for example, the lilacs — results in a drastic reduction in flowering.

LOCALIZATION OF PRUNING INFLUENCE

Small plants of comparatively simple structure — that is, plants that have a single tap root, like the radish, or a single unbranched stem, like the stock (*Mathiola incana*), or a single rosette of leaves, like the dandelion — or larger plants, like the cocoanut palm, that likewise have a comparatively simple structure, grow more or less as a unit. The entire top of stem and leaves is quickly and uniformly influenced by what happens to any part of the root system, and in turn root growth is influenced by what happens to leaves or stem. In other words, the several parts of the plant are almost completely interdependent. This is not true, however, of plants with a more complex structure, more especially plants with much-branched tops. Such plants are, in one sense at least, to be regarded more as plant colonies made up of competing individuals than as single units in which the welfare of each part depends on that of every other part. One branch of a grapevine or tomato plant, or maple or pear tree is in competition with all, or many, of the others for room in which to grow, for light, for water, and for mineral nutrients. If the others get less of any of these, it gets more; if the others get more, it gets less. For light and room and to a somewhat less extent for water and nutrients, its most severe competition is with its closest neighbors in the plant colony. What happens to members of the colony on the other side of the plant or a considerable distance away has little influence upon it. In other words, though subject to such general influences that affect all parts of the plant, such as drought, it is particularly subject to very local influences. Any individual pruning cut in a plant is necessarily localized, and though it may have some slight influence on the plant as a whole, its principal influence is on those shoots, branches, or other parts in close proximity to where it was made. This means that pruning must be done close to where the responses that it is hoped to obtain are wanted. If they are wanted on the north side or in the top or in the center of the plant, the pruning must be on the north side, in the top, or in the center, as the case may be. If they are wanted throughout the top of the tree, the pruning cuts must be distributed throughout the top. This, in turn, means that the removal of a comparatively large number of small branches will result in a more general response than will be obtained from the removal of an equivalent or even greater amount of wood in the form of a much smaller number of large branches.

SEASON OF YEAR FOR PRUNING

The season of year at which plants of different kinds are pruned is influenced by many factors. Some pruning is occasioned by breakage or other mechanical injury of certain branches, by their dying out or by localized insect or disease attack. There is little reason to delay such pruning until a certain season when most of the pruning is usually done; as a matter of fact, such delay may be dangerous. Some pruning is therefore done more or less throughout the year. Convenience and certain other practical considerations dictate that most of it be done at certain seasons. Obviously, it would be impracticable to prune plants grown for their flowers just before or during their blossoming season or fruit-producing plants while the crop is maturing, or even after the fruits have become half grown. With deciduous fruits the dormant season is utilized for most pruning operations. With the leaves off, the framework of the plant is in better view, and it is easier to determine which branches should be removed. Furthermore, at that season the fruit-grower himself has more time at his disposal for this operation than at most other seasons. On the other hand, many ornamentals can be pruned to best advantage during the active growing season. Were they pruned while dormant many flower buds would be removed and their attractiveness a little later materially reduced. By delaying pruning until immediately after flowering, maximum flower production is obtained, and then the unattractive, useless fruiting wood can be removed to make room for new growth on which the following season's flowers will be produced. The summer removal of useless watersprouts and suckers that otherwise would be pruned out the next spring is generally considered good practice.

PRUNING WOUNDS

The removal of any plant part in pruning leaves certain tissues exposed both to drying out and to the danger of infection by pathogenic organisms of many kinds. Quick drying of the exposed surfaces, followed by a natural plugging of the vessels with resin, gums, and other substances, and somewhat later, callus formation serves to seal in and protect the living tissues within and prevent the entrance of organisms of decay. These processes take time, however, and in the case of large surfaces occasioned by the removal of large branches some kind of artificial protection is desirable. A single coating of any wax, paint, or other waterproof material that is nonpenetrating and nontoxic to the plant's woody tissues is usually sufficient. Grafting wax and house paint make satisfactory wound dressings; asphaltum and various coal tar products have often been used but in many cases have resulted in as much injury as benefit. It is seldom necessary to paint wounds less than an inch or an inch and a half in diameter. One reason for pruning during the latter part of the dormant season is that the wounds usually heal more promptly than when made at other seasons.

PROBLEMS

1. In general, would you expect more, or less, pruning to be desirable with trees that are grown for their seeds rather than for their fruits? Why?

2. In general, would you expect more, or less, pruning to be required by plants grown for cut flowers than by those grown as "potted plants" or for their general landscape effect? Why?

3. Locate two trees (of different species and of different sizes) and two shrubs (likewise of different species and different sizes) that presumably were planted many years ago and at about the same time near some long since abandoned building. Estimate their ages and sizes. Examine them to determine why they differ in size (one tree from another, one shrub from another, and tree from shrub). To what extent are the differences to be attributed to such factors as: (*a*) rate of growth, (*b*) injuries from pests, (*c*) location and soil, (*d*) natural pruning.

4. Locate a hedge that has been given regular pruning and some plants of the same kind and age that have not been pruned. Compare them from the standpoints of: (*a*) size of individual plants, (*b*) size of leaves, (*c*) length and apparent vigor of new shoot growth. Explain the observations you make.

5. Would you expect the average hedge pruned as it must be to keep it "in bounds" to be more or less productive of flowers than plants of the same kind not pruned? Why?

6. We often see it stated that severe pruning will serve to "invigorate" a plant. Is this more likely with flowering, weakly vegetative plants or with non-flowering plants that are equally weak? Why?

7. Pears, apples, and sweet cherries form their flower buds and bear principally on spurs; peaches and grapes form their flower buds and bear principally on shoots. Which of these two groups or classes of fruits do you think can and should be pruned the more heavily? Explain.

8. More of a premium is paid for large size of fruit in the case of peaches than in the case of sour cherries. Would you think this makes any difference in the amount or severity of pruning that should be accorded the two kinds of trees? Explain.

9. In view of the fact that the general effect of moderate to heavy pruning of bearing blueberry plants is to increase size of fruit, lower total yield, and cause earlier maturity, should North Carolina and New Jersey growers of this fruit be given the same pruning recommendations as growers in Massachusetts and Michigan? Explain.

10. (*a*) In general would you think that grapes being grown for wineries and grape-juice factories should be pruned more or less severely than those being grown as table stock? Explain. (*b*) Is the answer the same for plums being grown for table stock, as contrasted with those being grown for drying into prunes? Explain.

CHAPTER XV

FLOWERS, FRUITS, AND SEEDS

IN THE chapter on "Growth and Fruitfulness" mention was made of the fact that some crop plants are cultivated primarily for their vegetative parts. Head lettuce, asparagus, the rex begonias, tea, and sugar cane are illustrative of the great diversity in this group, if such it may be called. On the other hand, the great majority of cultivated plants are grown for their flowers, fruits, or seeds. Consequently, much of the effort that is given to their culture is for the purpose of promoting the best development of those structures or organs associated with, or the products of, reproduction.

OBTAINING FLOWERS FROM FLOWER BUDS

The development of the rudimentary or embryo flower parts within the flower bud, after flower-bud differentiation has once taken place, and the later opening of that bud to form a flower cluster with its individual flowers is an entirely natural process or series of processes. Seldom is it necessary to give it any thought. It takes place without any help or attention on the part of the cultivator — indeed, it is very likely to take place in spite of anything he might be able to do to prevent it, either intentionally or unintentionally. On the other hand, the old adage to the effect that "there is many a slip betwixt cup and lip" applies here, for there are many plants with which certain unfavorable conditions between the time of flower-bud differentiation and flowering are of rather frequent occurrence. Brief reference will be made to some of these factors and methods of dealing with them.

TEMPERATURE INFLUENCES

In the case of many woody perennials that produce flowers one year from flower buds differentiated the preceding year and that are grown in sections with a rather severe intervening winter season there is danger of winterkilling. When the flower buds are more tender to winter cold than the leaf buds or shoots of the same plant — well illustrated by the peach among fruits and by the golden bell (*Forsythia suspensa fortunei*) among ornamentals — the plant may show no injury in its vegetative parts and make a normal growth in the spring, but it produces no flowers. The amateur often mistakenly attributes the failure to blossom to a failure to form flower buds and seeks to remedy the situation by pruning practices, irrigation, or fertilizer applications that are as likely to increase as to decrease the susceptibility of the buds to low temperature injury the following winter. Choice of varieties, whose flower buds are comparatively resistant to winter injury, and such cultural practices as will lead to the initiation, but not overdevelopment, of flower buds as the plant goes into the dormant season are the two principal measures at the grower's disposal to reduce flower-bud losses of this type. In some instances, however, protection against winter cold is obtained by laying or bending the plant or its branches to the ground and covering with soil, straw, or other material that will serve as a blanket and keep its flower buds from exposure to extremes of temperature. Measures of this kind are relatively costly and usually warranted only with highly valued ornamentals.

It is not low winter temperature alone that destroys flower buds between the time of their differentiation and the time of their opening into flowers. In some species high temperature may have a similar influence. Thus, in the greenhouse culture of the gardenia (*Gardenia veitchii*) it is important to maintain night temperatures well below 60° F. during their more or less continuous flowering period; otherwise, the partially grown flower buds abscise, and no flowers are formed.

PHOTOPERIODIC INFLUENCES

In the chapter on "Growth and Fruitfulness," attention was called to the fact that in many species and varieties the change from a vegetative to a reproductive condition depends on length of day. In the so-called *short-day* plants flower-bud initiation occurs only when the days are relatively short, in the *long-day* plants only when they are relatively long. In some plants length of day also determines whether flower buds that have been initiated will or will not continue to develop and reach the flowering stage.

In the gardenia, just mentioned under "Temperature Influences," partially grown flower buds turn yellow and abscise in northern greenhouses during the short days of winter, even though temperature, soil, humidity, and light intensity are favorable for growth and flowering. If the daylight period is lengthened sufficiently (two or three hours) each day, the flower buds open, and flowers develop normally.

A somewhat similar response to photoperiod is sometimes exhibited by the developing flowers of a number of strawberry varieties. When their flower buds and flowers develop during the lengthening days of mid and late spring, perfect flowers with normal stamens and pistils are formed; when these same varieties are forced to blossom in the greenhouse in the short days of winter or when they are grown outdoors in a section where blossoming normally occurs during the short-day season, their flowers are without stamens.

Still another kind of photoperiodic influence on flower development is seen in the *cleistogamous* (that is, nonopening and self-pollinating) flowers of a number of species. During the moderately long days of early and mid-spring, the flowers of many kinds of violets and of some pansies develop "normally," with the large showy petals for which they are prized. During the somewhat longer days of late spring and early summer, however, the petals in the flower buds of these same plants remain rudimentary, and the buds themselves fail to open, though self-pollination takes place, and seeds are freely formed. With other species short, rather than long, days lead to cleistogamy. Thus, in the spring, summer, and early fall months the flowers of *Neomammillaria prolifera* (a diminutive, ornamental cactus shown in Figure 135) open normally, but fail to set fruits even though carefully pollinated; in the short days of late fall and winter, they fail to open, but set fruits freely. In this latter instance, it is the cleistogamous flowers that are really useful to the cultivator, for the plant is prized for its brilliant scarlet fruits rather than for its flowers. In *Viola sepincola* cleistogamous flowers only are formed when grown in dense shade; flowers that open are formed in sunny locations.

"SLEEPING" FLOWERS

Failure of flowers to open is not due solely, or even principally, to length-of-day influences. The flowers of some plants (for example, *Ammannia latifolia*) are regularly, rather than temporarily or periodically, cleistogamous. Seldom are such plants grown for the decorative or ornamental value of their flowers, though the character of their foliage may be such that they are grown as ornamentals. On the other hand, the full-sized but unopened flowers of certain species and varieties may be quite as attractive as the wide-open flowers of related kinds. Illustrative of this group are some of the so-called "sleeping" varieties of *Hibiscus* (see Figures 117 and 118). The flowers of many plants, such as the morning-glory (*Ipomoea hederacea*), open in the morning, remain open a few hours or perhaps all day and then close at night. Those of other species, such as the night-blooming cereus (*Hylocereus calcaratus*), open at night and close during the day, and continue this alternate opening and closing until pollinated or until the flowers start to fade and finally abscise. There are both night-blooming and day-blooming varieties of water lilies. This behavior may be regarded as a modified or special form of the "sleeping" habit. In these instances, failure of the flowers to open at all or to open fully or to remain open as long as they last, is to be regarded as an inherited varietal characteristic rather than as due in any way to environmental factors.

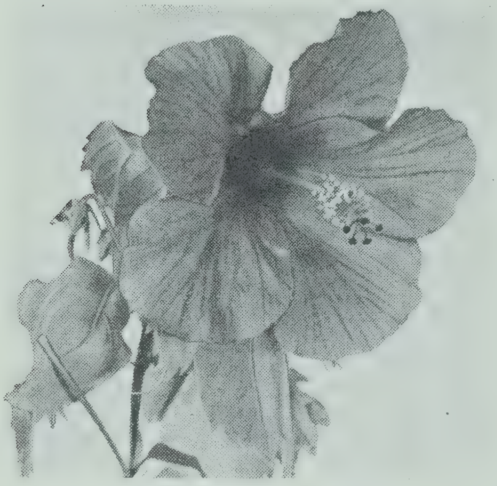


FIG. 117. An open flower of an ordinary variety of Hibiscus (*Hibiscus rosa-sinensis*). Compare with Figure 118.

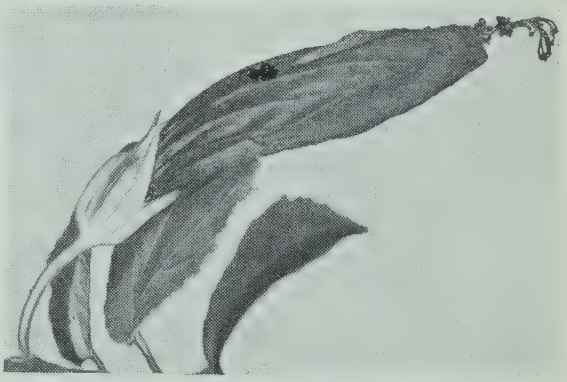


FIG. 118. A "sleeping" flower of Hibiscus (*Hibiscus rosa-sinensis*). Compare with Figure 117.

NUTRITIONAL INFLUENCES

In a preceding chapter the statement was made that flower-bud differentiation depends on the accumulation of a certain minimum reserve of foods, principally carbohydrates. Without such a reserve, no flower buds will be initiated, and with only limited reserves their number will be small. Similarly, when food reserves are very limited in amount, many of the flower buds that are differentiated fail to develop into flowers. Ample evidence of food supply being a limiting factor in flower development may be seen in the flower clusters of many species, especially in those with a so-called *indeterminate* type of inflorescence, that is, a flower cluster in which the basal flowers develop first and those further up or out on the cluster develop and open later. Seldom do *all* of the individual flower buds in the inflorescence of the strawberry or raspberry, the tomato (Figure 119), larkspur (*Delphinium grandiflorum*), or gladiolus attain full size and develop into flowers. Food reserves and supplies being currently manufactured are all utilized by the more favorably situated flower buds and flowers that open first, and the last ones to develop abort. Indeed, it is generally food supply (operating, of course, within certain rather wide limits set by the inherited characteristics of the plant), rather than a failure in the differentiation of flower buds, that sets the limit to size of flower cluster and number of flowers. This is well illustrated by the numbers of flower buds commonly found on relatively strong and relatively weak red raspberry shoots.

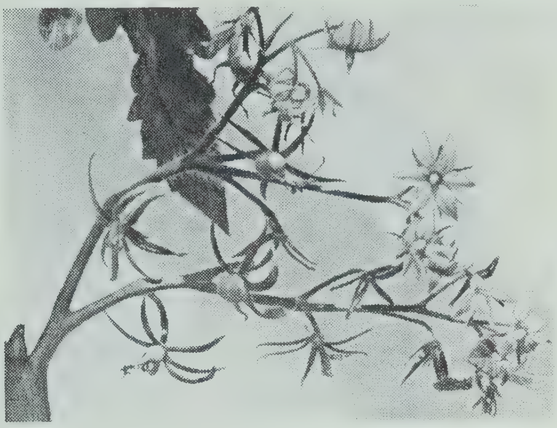


FIG. 119. An *indeterminate* flower cluster of the tomato. Under favorable growing conditions flowers continue to be produced near the terminal of the cluster long after fruits have set at its base. Sooner or later they stop forming, and the later formed flowers fail to set when the developing fruits utilize all of the available food supply.

In addition to the quantity or general level of food reserves, principally carbohydrates, limiting the development of flower buds already initiated and the consequent number of flowers, as mentioned in the preceding paragraph, deficiencies of certain elements may result in an abortion or abscission of partly developed flower buds. Thus, boron deficiency has been shown to be a cause of the "blasting" of the flower buds of cotton, and a very limited supply of nitrogen or potash or phosphorus may lead to poor setting in other instances. Poor setting in the common field bean because of potash deficiency is shown in Figure 120.

With many ornamentals, for example, the snapdragon (*Antirrhinum majus*) and stock (*Mathiola incana*), size of flower cluster and number of flowers largely determine their value. On the other hand, with many other kinds individual flower size counts for more than flower number or size of cluster. Roses, carnations, asters, and peonies are examples of a very large group in which a single flower is preferred to two or more on a stem, especially when grown for "cut-flower" purposes. With them individual flower size depends largely on food supply, just as flower-cluster size does in the other group, and maximum size is attained only with the aid of *disbudding*, a special type of pruning which consists in the early removal of some of the partially grown buds so as to divert into those that remain the full food reserves and food-manufacturing abilities of the plant. Disbudding is a regular

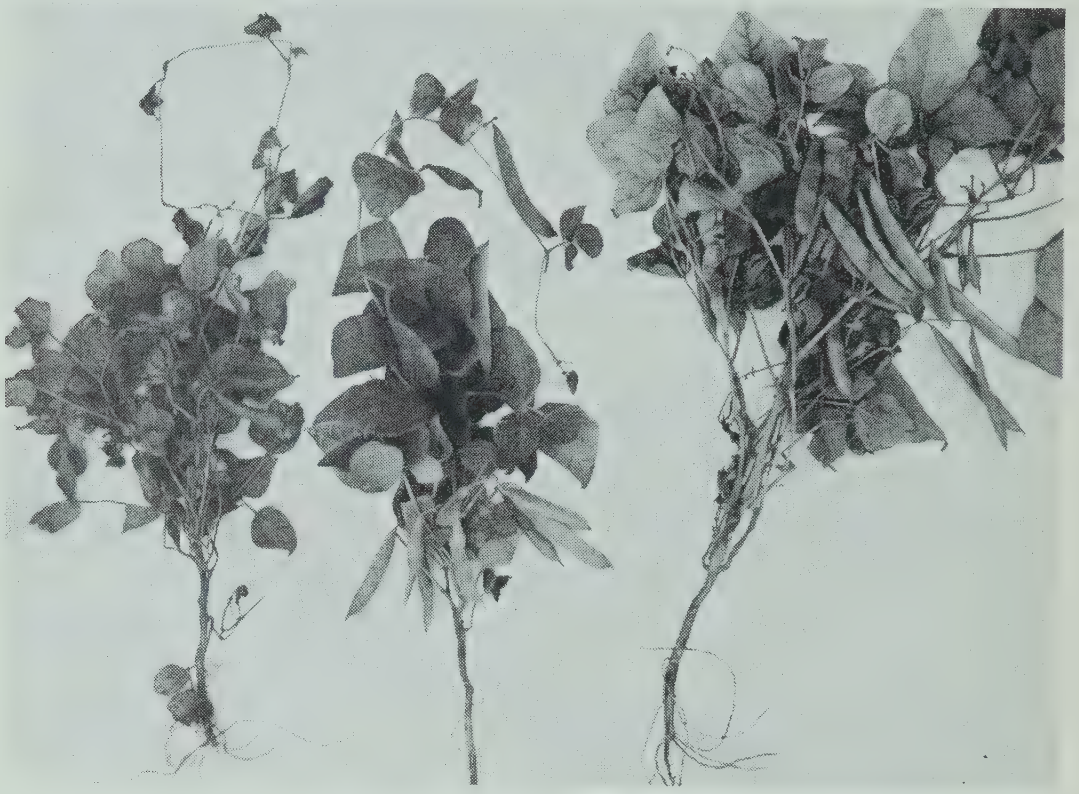


Fig. 120. Bean plants grown in a rather infertile soil. The one on the left was from a plot that was fertilized with phosphate only and set only two pods; the one in the center was from a plot that received potash only and set nine pods; the one on the right was from a plot that received both phosphate and potash and set fourteen pods.

practice in the greenhouse culture of many flower crops and is likewise important in the successful outdoor culture of many others.

KEEPING QUALITIES OF FLOWERS

The flowers of some species remain open for only a few hours. Those of certain kinds, for example, the night-blooming cereus of the Southwest (*Hylocereus calcaratus*), open only at night; those of others, for example, the morning-glory (*Ipomoea hederacea*) open in the morning and close before midday. Though some of these short-blooming kinds are among the showiest in the entire plant kingdom, they are of little use as cut flowers and are of comparatively limited value for other ornamental purposes. On the other hand, the flowers of many species have very good lasting qualities. Carnations, chrysanthemums, snapdragons, asters, gladioli, and many others will ordinarily last a week or more; roses, violets, sweet peas, and dahlias are likely to fade or wilt within three or four days. The flowers of a few species, for example, the Indian bell (*Bryophyllum calycinum*), statice (*Statice armeria*), and several species of *Kalanchoë* last for three or four weeks or more while attached to the parent plant and nearly as long as cut flowers. The so-called *everlastings* (*Helichrysum bracteatum*, *Ammobium alatum*, and *Helipterum roseum*) retain their color and form upon drying and are good for decorative purposes for months. Lasting quality of flowers is largely a specific or varietal characteristic, though long keeping may be aided by holding at a relatively low temperature and by plunging them immediately after cutting into cold water deep enough so that most of their stems are submerged. Little can be told regarding the keeping quality of flowers from their general appearance. For instance, the flowers of the gardenia (*Gardenia veitchii*) and the camellia (*Camellia japonica*) bear at least a superficial resemblance to each other; yet the former lasts but for a day or two, the latter for a week or more.

Pollination of many flowers is rather promptly followed by shedding or shriveling of the petals or sepals. If pollination is prevented, the flowers retain their fresh appearance much longer. In the case of the Easter lily (*Lilium longiflorum*) and a number of the members of *Amaryllis*, artificial removal of stamens as the buds are opening is often practiced to prevent pollination and prolong the life of the flower. One reason why orchids retain their freshness so long as cut flowers is that, as grown under cultivation, they are seldom pollinated.

COLORED BRACTS

In some species, as the poinsettia (*Poinsettia pulcherrima*), calla lily (*Zantedeschia aethiopica*), and bougainvillea (*Bougainvillaea glabra*), the colored, showy parts of the "flower" are not true floral structures but bracts or specialized leaves. In nature they serve the same purpose as petals or sepals in the flowers of other species, namely, to attract insect visitors. They also give the plant the decorative value that lies in the color, texture, and form of the flowers and flower clusters of other plants. In some species, as the two just mentioned, the colored bracts immediately subtend the true, inconspicuous flowers and are so closely associated with them that they give the general appearance of being flower parts (see Figure 121). In others, as snow-on-the-mountain (*Euphorbia marginata*), they are attached at points considerably below the flowers or perhaps at the base of fairly long pedicels or peduncles,

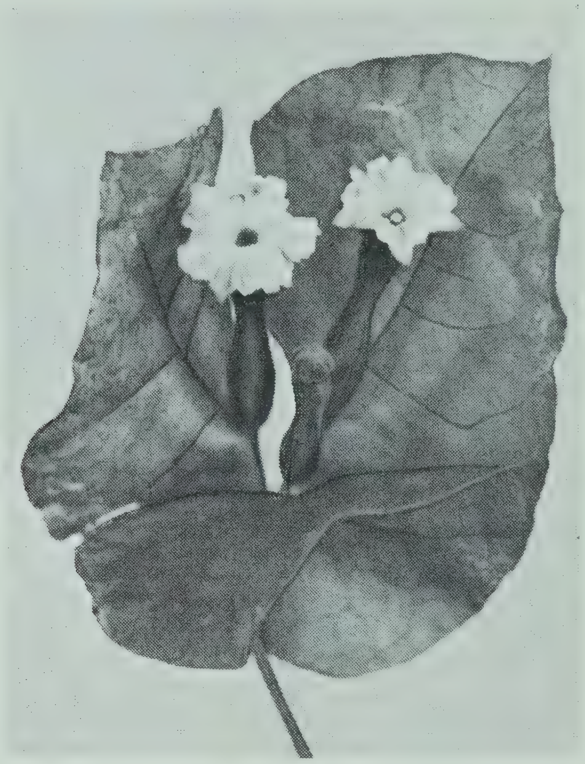


Fig. 121. The "flower" of the *Bougainvillaea*. In reality this is a cluster of three flowers (two open flowers and one flower bud, as shown here), that are relatively inconspicuous. These are surrounded by three showy bracts that in this black and white reproduction somewhat resemble leaves.

and there is no mistaking their identity. Nevertheless, they function in the same general capacity as means to attract pollinating insects or, when grown in the garden or greenhouse, provide the color values for which the plant is cultivated.

Only a step removed from the colored bracts intimately associated with the flowers and flower clusters of many plants are the colored leaves of such plants as the star snowbush (*Phyllanthus nivosus*) and its several horticultural varieties in which only the more basal leaves on the shoots are of the normal green while those of the distal sections of the shoots are white, pink, golden, or some other color. Leaves of this latter type usually closely resemble the green leaves of the same plants in size and shape, while the colored bracts more closely associated with the flowers themselves are likely to be entirely different in size and shape.

DOUBLE FLOWERS

In one of the two main subdivisions (the *dicotyledons*) of flowering plants the flowers are constructed on the basis of the number 5; in the other main subdivision (the *monocotyledons*) the flowers are constructed on the basis of the number 3. That is, in the first group the flowers characteristically have five stamens, five petals, five sepals, or multiples of 5, and, if there are not five pistils, the single pistil will be five-parted or five-lobed. In the second group, the several organs characteristically consist of three stamens, three petals, etc., or multiples thereof. If the petals or sepals do not exceed 10, 15, or perhaps 20 or 25 in the one group, or 12, 15, or perhaps 18, 21, or 24 in the other, they usually form a fairly distinct circle or whorl surrounding a more or less open center in which there may be few or many stamens and pistils. Such flowers are commonly spoken of as *single*. Where the petals and sepals much exceed these numbers and more or less fill up the space occupied by stamens and pistils in typically single flowers, we have what are called *double* flowers. Between the so-called single and double flowers, however, there is no sharp line. We may have completely double or semidouble flowers or those that are generally classified as single but that show some tendency toward doubling, such as those of the peony shown in Figure 122. Doubling may be due to: (*a*) simply an increase in the number of parts in the petal or sepal whorl, without any decrease in the number of stamens and pistils; (*b*) a replacement or substitution of stamens or pistils by petals or sepals; or (*c*) as in the composite family, a replacement of disc florets with ray or strap florets. Occasional doubling is a natural occurrence in many species, much more common in some than in others. Seldom does a plant of a species or variety that characteristically bears single flowers produce completely double flowers; instead it may bear a few semidouble flowers or single flowers that show some tendency toward doubling. If seeds of these plants are saved and seedlings grown from them, some may show a somewhat more marked tendency toward doubling, and in the course of several generations it may be possible by selection to develop a completely double variety or race. Theoretically, it is possible to develop double-flowered varieties or races of all species; in reality, they have been developed in many species but not in all.

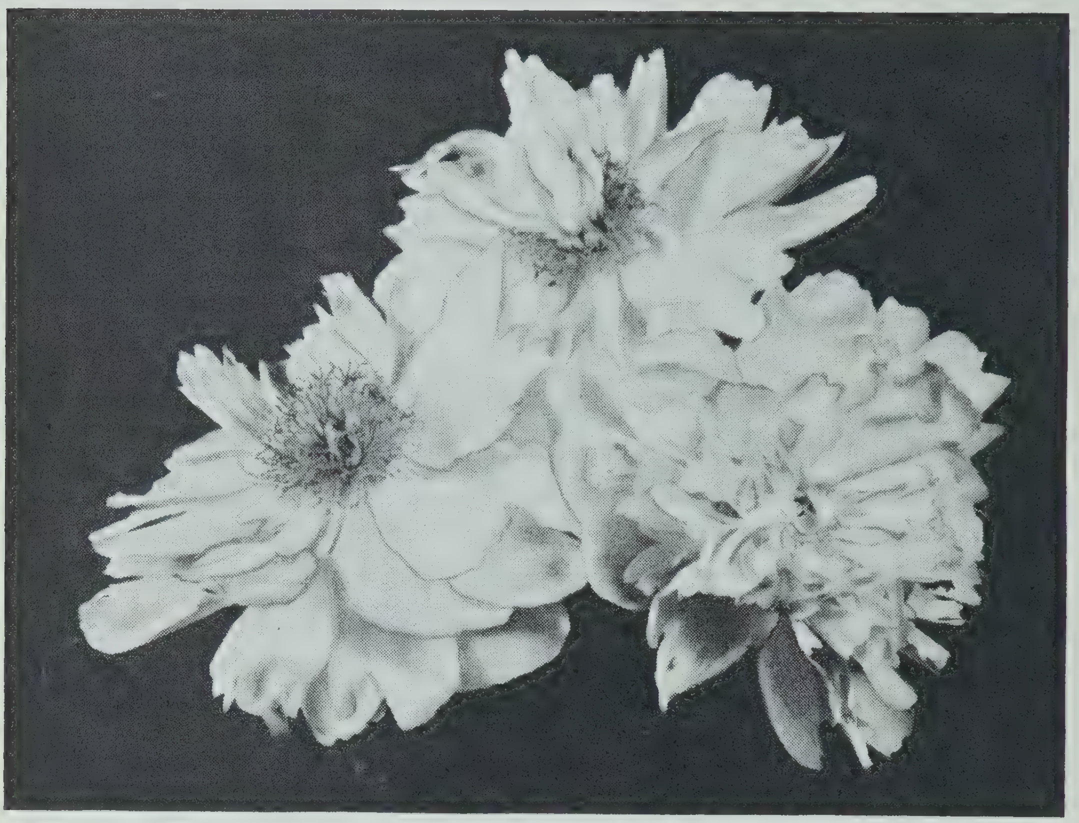


FIG. 122. Three flowers from the same peony plant. The one on the left would be classed as a *single*, the one on the right as a *double*, and the one in the center as a *semidouble*.

Double flowers are regarded as more attractive than single flowers in some plants — for example, the carnation (*Dianthus caryophyllus*), the rose (*Rosa indica*), and the gardenia (*Gardenia veitchii*). In many other species — for example, the morning-glory (*Ipomoea hederacea*) and the Easter lily (*Lilium longiflorum*) — double flowers are unknown or very rare and probably would not be wanted were they to be developed by breeding. In still other species — for example, the peony (*Paeonia albflora*), the chrysanthemum (*Chrysanthemum hortorum*), and the narcissus (*Narcissus pseudonarcissus*) both single and double varieties have been developed and on the whole are equally prized, though styles change and for a time or in some sections the one type may be grown almost exclusively, only to lose favor and be replaced by the other type a little later or somewhere else.

For the most part, doubling can be influenced to only a slight extent by cultural treatment, high fertility and intensive culture in general tending to promote it. It is the result of natural variation or of long continued breeding, and if double flowers are wanted, double-flowered varieties should be grown. Certain varieties of the stock (*Mathiola incana*) present a type of dimorphism in respect to flower doubling (see Figure 86). No seeds are produced by the double flowers, and seedlings must be raised from single-flowering plants. Some of the single-flowered plants are what the geneticist calls *homozygous* or pure for the single-flower characteristic; others carry genes for both single flowering and double flowering, and the double-flowered individuals develop from seeds resulting from the selfing or intercrossing of the flowers of such plants. It thus has been impossible to develop a variety or strain that is pure for double flowering, all seed stocks producing a considerable percentage of single-flowered individuals.

FRUIT SETTING AND FRUIT DEVELOPMENT

In the life cycle of plants as they grow naturally flowers are a means to reproduction, the antecedents of fruits and seeds, and normally flowering is promptly followed by fruit setting. In many plants practically every flower "sets," and a fruit develops in its place. This is true in many grains and grasses, in many garden vegetables like the radish and beet, in many annual, biennial, and perennial flowers like the morning-glory (*Ipomoea hederacea*), hollyhock (*Althaea rosea*), and tulip (*Tulipa gesneriana*). In many other plants half or more of the flowers characteristically fail to set; in some, as the mango (*Mangifera indica*), the percentage that sets is very small. To a large degree these broad differences in the setting of flowers, well illustrated in Figures 123 and 124, are species or variety characteristics that are inherited, and little can be done to change them. For instance, it is almost inconceivable that the flowers of the wheat plant should set as sparingly as those of the mango or that the flowers of the mango should set as completely as those of the wheat plant. Were they to do so, the wheat field would yield less than a peck of grain to the acre, and the mango tree would bear so heavily that it would break to pieces with the weight of its crop. On the other hand, within the ranges of flower setting commonly shown by a single species or variety — for example, from 3 to 30 per cent in the sour cherry (*Prunus cerasus*) or 50 to 100 per cent in the red raspberry

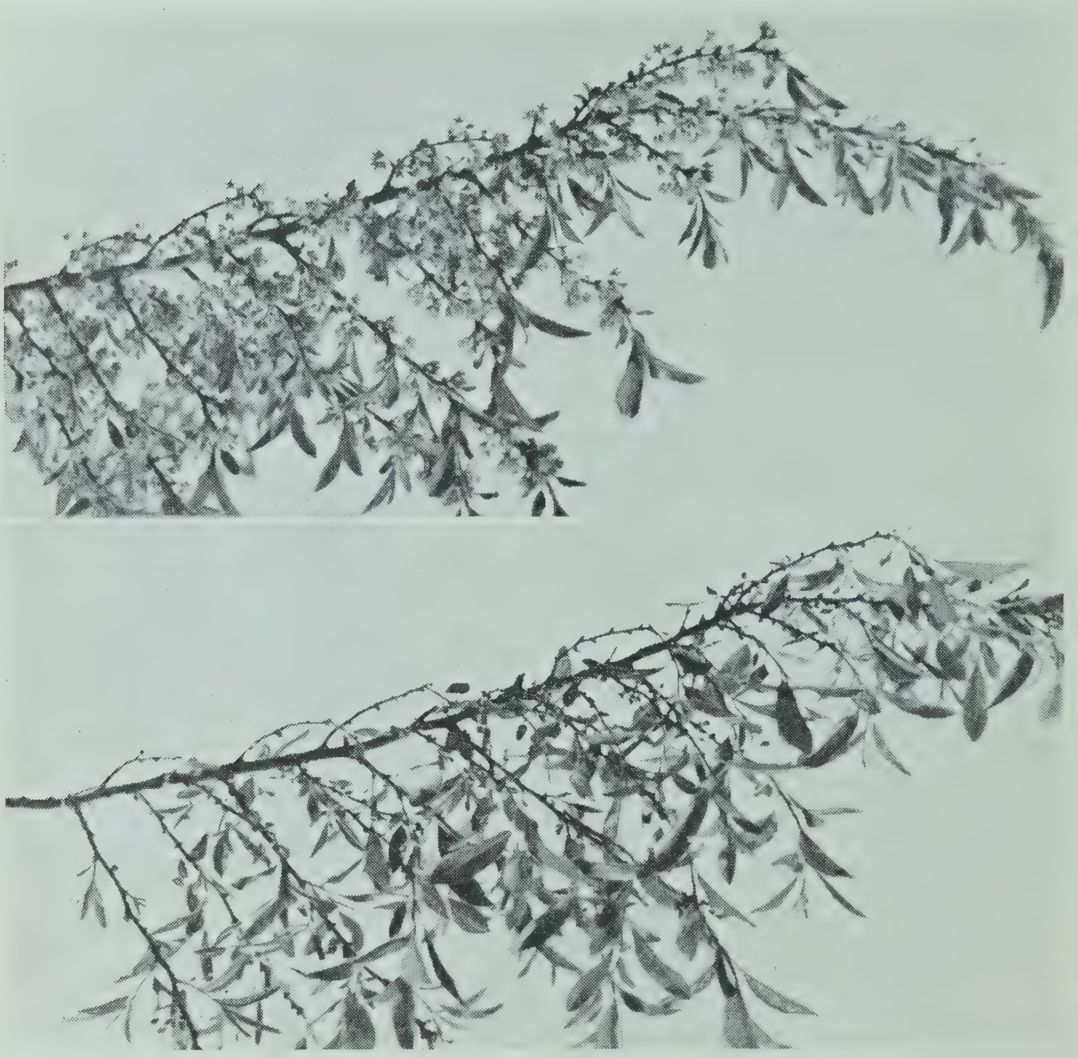


Fig. 123. Above is a small branch of the Wyant plum that had 1,827 flowers; below is a photograph of the same branch taken two weeks later, after the initial drop, when it carried thirteen swollen ovaries that gave promise of developing into fruits. Actually only three reached maturity. Compare with Figure 124.

(*Rubus strigosus*) or 1 to 10 per cent in the Japanese plum (*Prunus triflora*) — setting is subject to both internal and environmental conditions that are at least in part under the control of the cultivator.

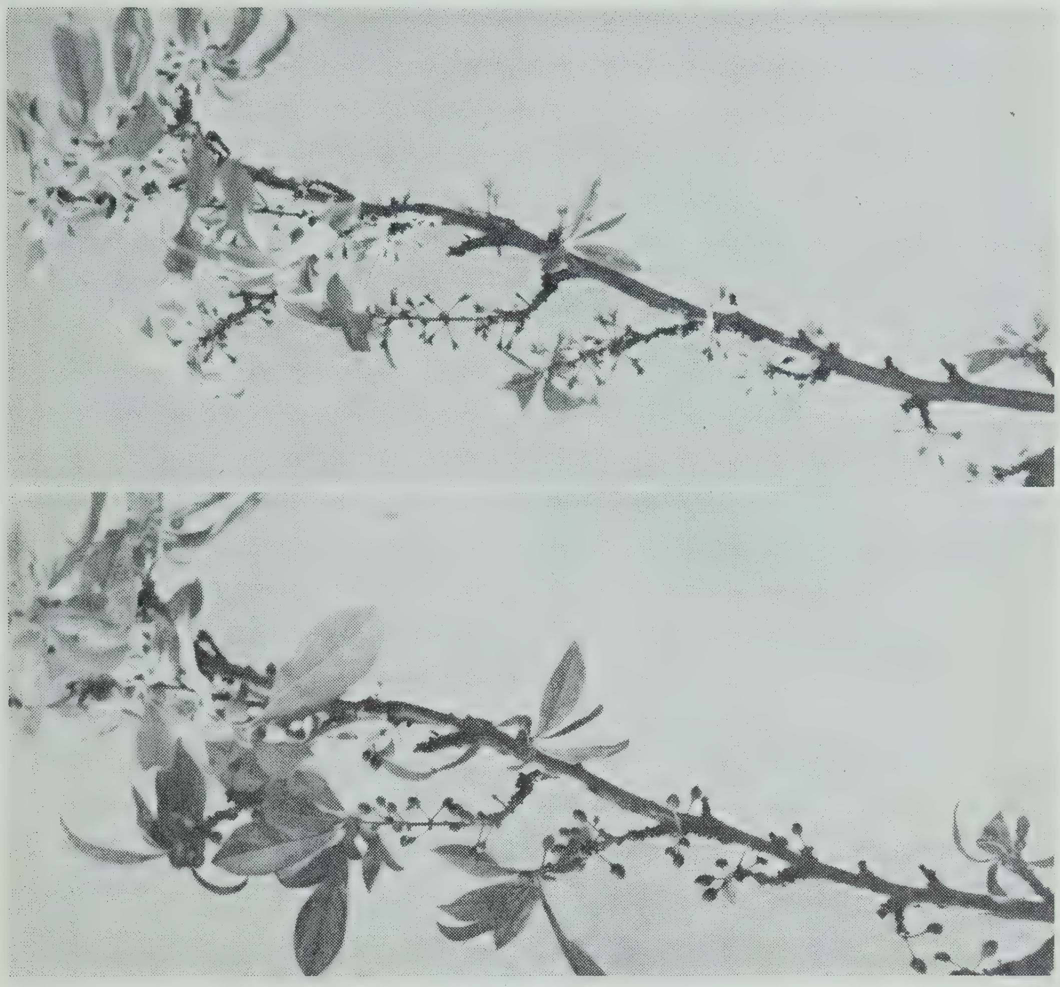


Fig. 124. Above is a branch of the Burbank plum that had 214 flowers; below is a photograph of the same branch two weeks later, after the initial drop, when it carried ninety-nine swollen ovaries that gave promise of developing into fruits. Actually only ten reached maturity, eighty-nine falling at the time of the June drop. Compare with Figure 123.

UNISEXUAL AND PERFECT FLOWERS

The flowers of many plants are *perfect* or *hermaphroditic* — that is, they contain both stamens and pistils. If properly pollinated, they can and do "set," provided, of course, that lack of food or some other factor does not interfere. Flowers of many other plants are *imperfect* or *unisexual*. Some of these are female or *pistillate* (Figure 125) and can set if properly pollinated; others are male or *staminate* (Figure 125) and, though necessary for the setting of the pistillate flowers, cannot themselves set fruit. In some species, as the melons and the cucumber (see Figure 87), there are several times as many staminate as pistillate flowers. In Indian corn (*Zea mays*) and the Norway maple (*Acer platanoides*) the pistillate flowers may outnumber the staminate kind. In many species, for example, the cucurbits and the walnuts, both pistillate and staminate flowers are borne on each and every plant and the plants themselves are *bisexual* or *monoecious*. In certain other species, *e.g.*, the mulberry (*Morus alba*), some of the figs (*Ficus carica*), and some of the strawberries, single plants, and consequently all the plants of certain varieties that trace back through vegetative propagation to single-seedling plants having this characteristic, bear flowers of only one sex. They are said to be *unisexual* or *dioecious*. Naturally, plants bearing staminate flowers only cannot set and bear fruit. The presence of a few scattered staminate individuals in a plantation consisting mainly of pistillate-flowered plants is necessary for flower setting and fruit production. Failure to recognize the unisexual nature of the flowers of certain fruit varieties has been responsible for many fruit-crop failures.

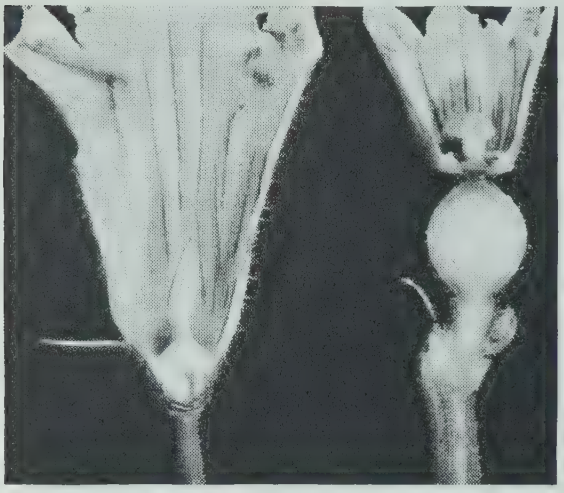


Fig. 125. On the left a staminate and on the right a pistillate flower of the squash.

Less obvious to many cultivators, but none the less effective, as a cause of crop failure because of the flowers not setting are those cases where the flowers seem to be perfect — that is, they contain both stamens and pistils — but in reality are imperfect. Their stamens are defective and bear either no pollen or only sterile pollen that is unable to fertilize the ovules of their own or any other pistillate flowers. This characteristic is found in many fruit varieties, for example, the Brighton grape (Figure 126), the J. H. Hale peach, and the Rhode Island Greening apple (a considerable portion of the pollen of this variety is defective). Such flowers, and also the varieties that bear them, could be classified as anatomically or structurally perfect or bisexual but physiologically imperfect or unisexual. Sometimes they are called *pseudo-hermaphroditic*.

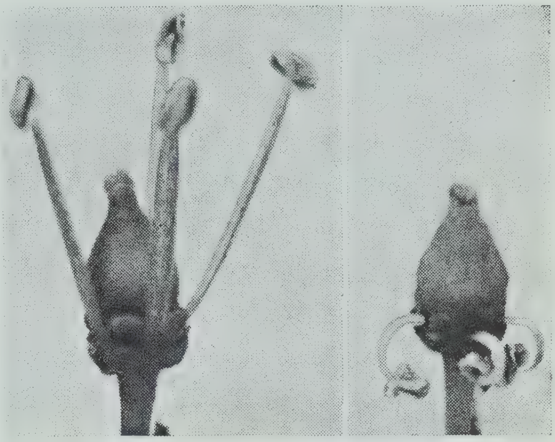


FIG. 126. On the left a perfect or hermaphrodite flower of the Concord grape. Note its erect stamens, which bear fertile pollen. On the right a pseudo-hermaphrodite flower of the Brighton grape. Note its reflexed stamens, which bear infertile pollen. Enlarged about six diameters.

In a practical way difficulties arising from the failure of individual plants or even the entire stock of certain varieties to set and mature fruits and seeds because of unisexual or pseudo-hermaphroditic flowers are encountered principally in plants grown for their edible fruits, such as certain varieties of grapes, Japanese persimmon (*Diospyros kaki*), the strawberry (*Fragaria chiloensis*), and the papaya (*Carica papaya*). However, many ornamentals are prized mainly because of their attractive fruits, and some of these species are dioecious. Thus, many an amateur gardener has planted a single specimen of the bittersweet vine (*Celastrus scandens*) to trail over garage or arbor, only to find when it reached flowering age that its flowers were either all staminate or all pistillate and hence unable to bear fruits until a plant of the other sex was planted near it to provide pollen or to provide pistillate flowers, as the case might be. The holly (*Ilex aquifolium*) is another example of a species in which the flowers of a single individual are of only one sex, and interplanting of the two sexes must be practiced in order to obtain berries. On the other hand, unisexual-flowered individuals or varieties of certain ornamentals are preferred to perfect-flowered individuals and varieties or to mixed plantings of the two sexes. In the United States the mulberry (*Morus alba*) is grown as a shade tree and to contribute a rather distinctive feature to the landscape. It is valued, however, principally for its luxuriant growth, its habit, and its rich, dark green, glossy foliage. Its fruits ripen over a long period, drop to the ground, and stain walks and drives. Unisexual plants can be obtained, and this objectionable feature entirely avoided.

INCOMPATIBILITY

Individual flowers or whole plants or whole varieties, as the case may be, producing either no pollen or defective, worthless pollen are unable to set fruit without the aid of pollen from some other flower, plant, or variety. They are often spoken of as being *self-unfruitful*, *self-barren*, or *self-sterile*. Those that can set and mature fruit without any such outside help are called *self-fruitful* or *self-productive*. If, in addition to maturing fruits, they are able to mature viable seeds, they are *self-fertile*.

Self-sterility is also found in some plants which bear perfect flowers, or both staminate and pistillate flowers on the same plant. Their pistils and pollen are entirely normal, but their pollen, for some reason, is unable to fertilize their own pistils or other pistils on the same plant (or pistils of other plants of the same vegetatively propagated variety), though it functions perfectly when used on the pistils of other plants, or other varieties, as the case may be. This type of self-sterility is called *self-incompatibility*. It is a characteristic of many varieties of fruits, for example, all sweet cherries and many varieties of apples and pears, and ornamentals. In most ornamentals it causes little trouble for they are grown for their flowers and foliage rather than for their fruits and seeds, and failure to set and develop fruit in no way detracts from their value. On the other hand, self-incompatibility has been the cause of untold crop losses in fruits. It was only about a half century ago that it was established as a factor of importance in the setting of fruit crops, and even now, because of ignorance, many fruit plantations are established without regard to it.

A less common type of incompatibility is that which characterizes *two* varieties, each of which bears fertile pistils and fertile pollen but whose pollens are mutually unacceptable to the pistils of the other variety. This is called *cross-incompatibility*. It is known to characterize certain pairs or combinations of varieties of the sweet cherry, pear, plum, and almond and likewise a number of ornamentals, such as the dahlia. Like self-incompatibility, it would not be likely to be found troublesome in the culture of most ornamentals, for only a relatively few are valued for their fruits and seeds.

DICHOGAMY

In the flowers of some plants the stamens and pistils do not mature simultaneously. The stamens may mature and shed all their pollen before the pistils become receptive, or the pistils may mature and pass through the receptive stage before the pollen is shed. Such a lack of synchronization in the maturing processes of the two sexes is known as *dichogamy*. If the stamens mature first, as in many filberts (*Corylus avellana*) and walnuts (*Juglans regia*), it is a case of *protandry;* if the pistils mature first, as in the calla lily (*Zantedeschia aethiopica*), it is a case of *protogyny*. Sometimes, as in the walnuts, the maturing seasons and receptive stages, respectively, of the two sexes may be separated by days; in other instances, as in the avocado (*Persea gratissima*), they may be separated by only an hour or two. In either case, however, if separation is complete, self-pollination cannot take place, and for all practical purposes the plant (or the variety, if vegetatively propagated) is self-barren and self-sterile. If there is some overlapping of the maturing season of the pollen and the receptive stage of the pistil, that is, if there is only partial dichogamy, the plant or the variety may be commercially self-fruitful and self-fertile. Partial is far more common than complete dichogamy. It is a frequent cause of *light*, as contrasted with *heavy*, setting.

PLANTING TO SECURE CROSS-POLLINATION

Obviously the remedy for structural or physiological peculiarities of flowers which interfere with pollination and setting, whether the peculiarity is unisexuality, pseudohermaphroditism, incompatibility, or dichogamy, is so to interplant different varieties that proper cross-pollination is possible. The number of fruit crops and varieties, especially those produced on trees, with which this is necessary exceeds those for which it is unnecessary. Indeed, a good rule is always to plant so as to secure the benefits of cross-pollination unless definite information is available that the variety in question is self-fruitful. Then no such precaution is necessary, and the solid planting of a single kind may present some advantages from the standpoint of harvesting, marketing, spraying, or other features of culture. It is seldom necessary, however, to plant equal numbers of the two kinds. If one kind is more valuable than the other, one plant or one row of the less valuable kind to three or four of the more valuable may be entirely adequate to provide satisfactory pollination. Sometimes the ratio of pollenizing to main kind can be reduced to every third or even fourth plant in every third or fourth row.

When planting has been done without due reference to cross-pollination and the plants have reached bearing age, the mistake can often be remedied more economically by grafting over enough plants to a suitable pollenizing variety than by the removal of an equal number and resetting. The grafts are likely to attain blossoming and bearing age long before the replants.

A somewhat bothersome, but nevertheless effective, remedial measure in a self-unfruitful plantation is to introduce flowering branches of some *intercompatible* variety during the flowering season for the purpose of supplying pollen. These flowering branches can be stood in pails of water to keep them fresh, and the pails then are set on the ground between the trees, as in Figure 56, or placed in the crotches or suspended from the branches of the trees. Such measures should be regarded simply as temporary expedients to provide cross-pollination, secure a set, and provide for crops while top grafts are being set and grow to blossoming age.

POLLINATION

Pollination has been mentioned repeatedly in the preceding paragraphs as a necessary antecedent to setting. Many cultivators think of pollination as not only a natural but a more or less automatic process, one to which certainly they need give no attention. Their failure to give it the consideration it sometimes requires often is a cause of poor setting and consequent crop failure. This is well illustrated by the cherry branches shown in Figure 127. Transfer of pollen from stamen to *stigma*, the receptive tip of the pistil, indeed, is automatic in some plants. That is, the pollen as it is shed from the stamens falls upon the receptive stigmatic surfaces of the same flower, or the stamens may bend over and deposit their pollen upon mechanical contact with the stigmas. This type of self-pollination is called *autogamy*. It characterizes the flowers of the oat (*Avena sativa*), violet (*Viola sepincola*), bean (*Phaseolus vulgaris* and *P. lunatus*), most tomatoes (*Lycopersicon esculentum*), and many other plants. Obviously pollination itself is seldom a limiting factor in the setting of their flowers, though in the case of tomatoes grown in the greenhouse jarring of plants or some other method of loosening the pollen, or even actually artificially transferring it from stamen to stigma, may be necessary.

In many species pollen transfer is effected by the wind, and to the extent that most people think of the pollination process, they associate it with wind movement. Among the more common crop plants whose flowers are wind-pollinated are corn, wheat, beet, spinach, grape, walnut, chestnut, pecan, and filbert. Wind-borne pollen is often carried great distances, and consequently the matter of keeping seed stocks of varieties that are wind-pollinated free from admixtures caused by cross-pollination presents some difficulty. Either the plants must be isolated considerable distances from those of other varieties, or their flowers must be carefully bagged or otherwise protected from foreign pollen. On the other hand, self-unfruitful varieties of such wind-pollinated plants as the grape must be closely interplanted with their pollen supplying companions (say, one row of the pollinating variety to every five or six rows of the other kind) if a good set is to be obtained. Wind-pollinated flowers are known as *anemophilous;* they are seldom showy and seldom have pronounced aromas.

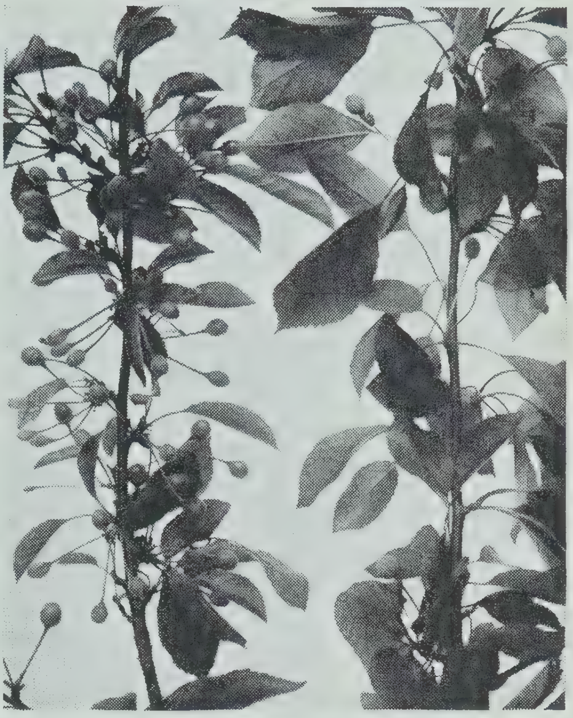


Fig. 127. Branches of a self-fertile variety of cherry. The one on the left was open to pollination by insects; the one on the right had been enclosed in a mesh bag to prevent insect visitation during blossoming.

The flowers of the great majority of our cultivated fruits, vegetables, flowers, and ornamentals are insect-pollinated. Those of many kinds are so constructed that many different species of insects regularly visit them and effect a transfer of pollen from stamens to stigmas of the same flower or carry pollen from one flower to another on the same or a different plant. Thus, upwards of fifty species of insects have been identified as visiting the flowers of the apple, and a careful watch of the flowers of most insect-pollinated plants for an hour or so when conditions are favorable for pollination is almost sure to reveal the visits of a half-dozen or more kinds. On the other hand, the flowers of some species are so constructed that only two or three kinds of insects, or perhaps only a single kind, can reach their stamens and stigmas and effect a pollen transfer. This condition is well-illustrated by the dependence of the red clover (*Trifolium pratense*) upon certain species of the bumblebee (*Bombus*).

A striking illustration of the dependence of certain plant species for the pollination of their flowers on a single insect species is afforded by certain pistillate-flowered varieties of the fig (*Ficus carica*). Eggs of the wasps (*Blastophaga*) that carry the pollen in this case are laid in the immature flower clusters of the *caprifig*, the name given to the perfect-flowered or staminate-flowered or monoecious individuals of this species. As the adult wasps leave the maturing flower clusters, they carry along with them more or less pollen which they, in turn, deposit on the stigmas of some of the pistillate flowers of the valuable cultivated fruit-bearing varieties, such as Smyrna. Pollen transfer can be effected only by this particular kind of wasp (*Blastophaga*) which feeds upon and spends most of its life within the developing flower cluster and flowers of the caprifig. In practice fig-growers generally plant their caprifigs some distance from their pistillate-flowered trees and then gather their flowers at the right stage and place a few of them in the pistillate trees so that their flowers will be pollinated, but not too heavily pollinated; otherwise, they would be too seedy. This particular type of artificial pollination has been practiced for many centuries and is known as *caprification*.

Such dependence of the flowers of a species on a single insect species for pollen transfer restricts the chances of their setting and maturing fruits and seeds, and apparently the prevalence and natural distribution of certain pollinating insects are the main factors in determining the natural range and the density of population of certain plant species. This latter relationship is illustrated by some of the orchids and a number of other groups characterized by highly specialized flower structures. Insect-pollinated flowers are said to be *entomophilous;* they are likely to be either showy or to possess aromas that attract the insects.

At first thought it would seem that the grower can do little to improve or control the setting of flowers that are insect-pollinated. Fortunately, the honeybee (see Figure 128) is a very efficient pollinating agent for the flowers of many different cultivated crops, ranging from alfalfa (*Medicago sativa*) and sweet clover (*Melilotus alba* and *M. officinalis*) among forage crops to apples and raspberries among fruits, cantaloupes, and radishes among vegetables and to mignonette (*Reseda odorata*) and nasturtium (*Tropaeolum majus*) among flowering ornamentals. If the

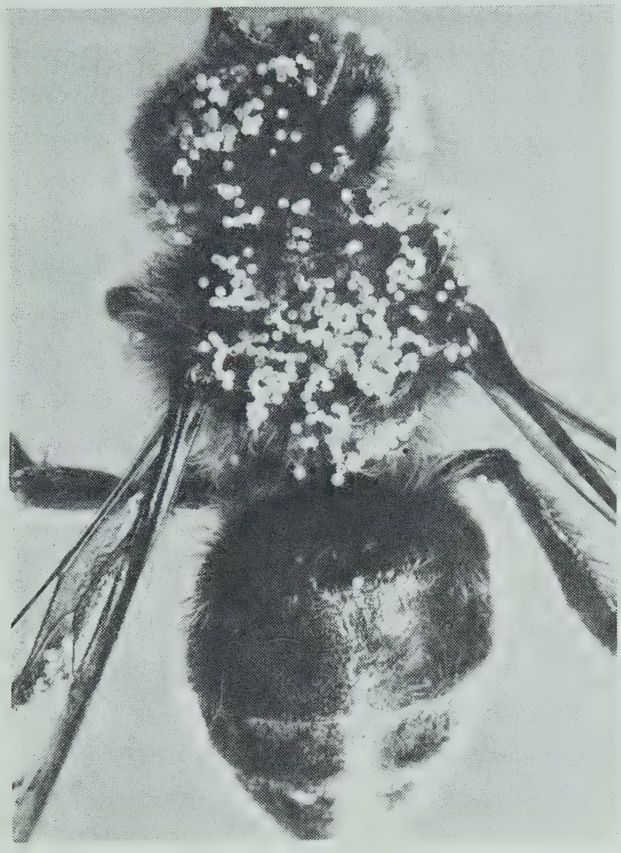


Fig. 128. An enlarged photograph of a honeybee, showing pollen grains clinging to it. The honeybee is one of the best pollen carriers.

honeybee population is light in the vicinity of an apple orchard planted to a self-fertile variety or a field where a crop of radish seed is being produced, setting will be poor and yields light. The situation can be remedied by maintaining a sufficient number of colonies of bees in close proximity to the orchards or fields in question. Making this provision for pollen transfer is as much a part of the regular procedure in connection with such enterprises as is pruning or spraying or cultivation. Spraying insect-pollinated plants while they are in bloom with arsenicals or certain other materials that are likely to poison bees or other pollinating insects is a dangerous practice, though one which, because of ignorance of its influence on setting, is employed altogether too often. On the other hand, it is possible and often desirable to spray plants while in flower with a nonpoisonous fungicide.

In some species transfer of pollen from stamens to stigma is effected by agents other than those already mentioned. Pollen of some of the hydrophytes falls on the water as it is discharged and floats on its surface. Some of it is carried by wind and water currents to the stigmas of other plants of the same kind. Hummingbirds live principally on the nectar that they obtain from the flowers of many species and are effective pollen carriers. Certain species, for example, the bird-of-paradise flower (*Strelitzia reginae*), shown in Figure 129, and some species of *Abutilon*, are said to be pollinated exclusively by birds. Artificial, hand pollination is commonly employed with some greenhouse-grown crops.

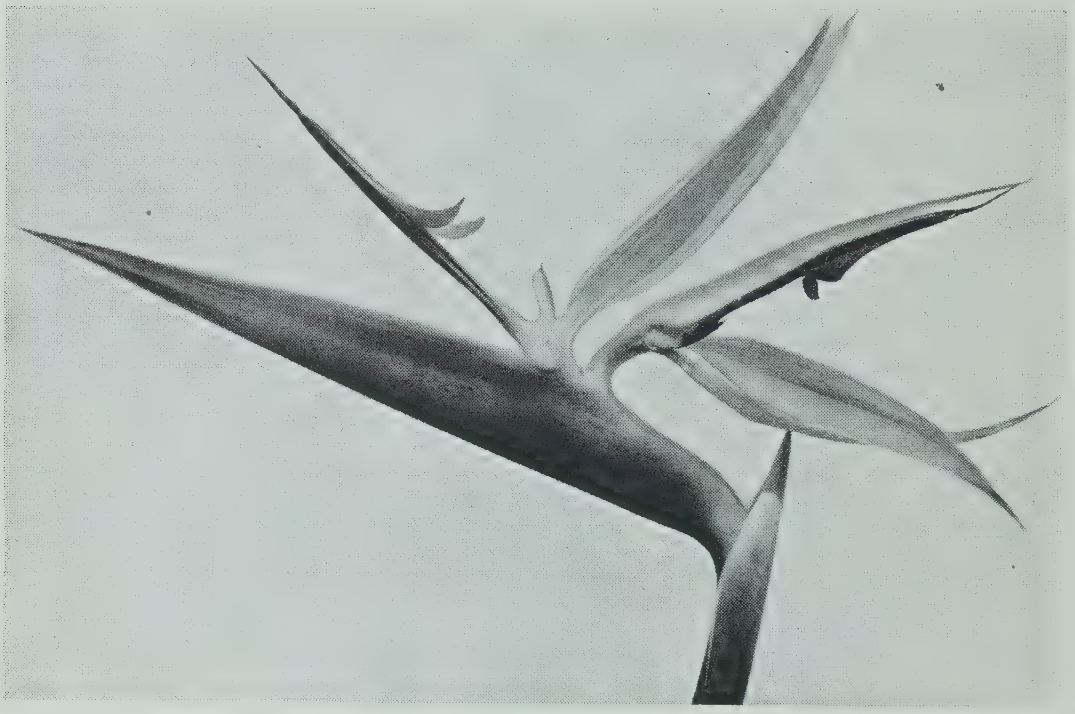


FIG. 129. A bird-of-paradise (*Strelitzia reginae*) flower, used in making corsages. It is pollinated by humming birds.

POLLEN GERMINATION AND FERTILIZATION

The pollen grain itself is a single cell, with a more or less thickened outer coat and a very thin inner coat surrounding the protoplasm with its nucleus or nuclei. Upon being deposited on the stigmatic surface of the pistil it germinates. Germination consists in a rupture or cracking of its outer coat and the extension of its protoplasm in the form of a tube that is encased or surrounded by the thin inner coat. This tube penetrates the style of the pistil and eventually reaches an ovule, which, in turn, is penetrated. One nucleus of the pollen grain then fuses with the nucleus of the egg cell of the ovule, this fusion constituting the *fertilization* process. In due course of time the embryo of the seed develops from these fused nuclei, and the *endosperm* of the seed is derived from the subsequent division and growth of the other pollen and embryo sac nuclei. If for some reason germination of the pollen grain and fertilization do not follow pollination fairly promptly, setting is not likely to take place, and the flower turns yellow and falls off.

NORMAL "SET" AND THE JUNE DROP

The statement was made that in some plants practically all of the flowers set; in others varying percentages characteristically fail to set. In some of the species and varieties in which considerable percentages fail to set, the failure occurs at the blossoming stage, withering or dropping off having taken place by the close of the blossoming period. This, for instance, is true of the flowers of the Japanese quince (*Cydonia japonica*), the garden pea (*Pisum sativum*), the mulberry (*Morus alba*). They either abscise promptly, or they set and proceed to develop and mature fruits and seeds.

In other species or varieties practically none of the flowers fail to set or *apparently* set at blossoming time. Uniformly their ovaries swell, and what seems like a full crop of fruits and seeds is in prospect, only to have a large percentage suddenly cease enlarging a week or two after blossoming or perhaps much later when a third- or half-grown (see Figure 124). This is often called a *June drop*, though it does not always occur in June. Sometimes there is a single wave of dropping, sometimes two or more. In some kinds there is one drop that occurs at the blossoming stage and then a June drop later. In other words, *initial* setting does not guarantee that a fruit will mature from each and every flower. Different factors are responsible for, or at least associated with, the June drop. In some instances, it is attributed to lack of pollination or pollination with incompatible pollen that is not followed by fertilization; in other instances it seems to be more closely associated with nutritive conditions within the plant or perhaps with certain environmental conditions about which more will be said later. In any case, it results in a thinning of the prospective crop of fruit and seeds, sometimes only in a light or moderate thinning, in other cases in a very severe thinning. Probably, on the whole, the June drop is advantageous to the plant and to the cultivator, for it tends to prevent overbearing and results in larger individual fruits and seeds than otherwise would be obtained. On the other hand, if extreme, June drop may result in substantial reductions in yield and consequent losses, and it is important for the cultivator to know as much about its nature, causes, and control as possible.

SETTING AND MOISTURE SUPPLY

The flowers of many species are especially sensitive to rainfall, soil moisture, and atmospheric humidity influences during the pollinating and setting period. Rain washes away and destroys much pollen, subjects the flowers to more or less mechanical battering, and interferes with the activity of pollen-carrying insects. Long continued rainfall, even though total precipitation is small, may greatly reduce or even entirely prevent setting and ruin crop prospects. This is one of the most serious of the fruit-grower's hazards and is one of the reasons for the heavier and more regular yields of certain crop varieties in dry as compared with humid regions.

On the other hand, low atmospheric humidity, when accompanied by high temperature and considerable wind, dries out the stigmatic secretions and surfaces and prevents the germination of the pollen grains. If extreme, it results in drying out of the flowers or flower clusters and in their abscission. This effect is often seen in the walnut and pecan, in the orange and lemon, and in tomatoes, peppers, and many other vegetable crops. Of equal or greater importance in preventing setting in many crops is limited soil moisture supply. The flowers of field, garden, and lima beans are particularly sensitive to drought. Those kinds that have a single short blossoming period may have their crop practically destroyed if it happens to coincide with a period of drought; those kinds that have an extended period of blossoming may have successive periods of good and poor setting corresponding with conditions of soil moisture.

Cultivation, especially that which is deep enough to destroy any considerable portion of the actively absorbing roots, during the blossoming and fruit-setting period is likely to be attended by the abscission of many flowers without setting, owing to a temporary reduction in the amount of water that the plant actually obtains from the soil. Undesirable effects from such cultivation have been noted in the case of cotton, tomatoes, and many of the fruit crops.

TEMPERATURE AND FRUIT SETTING

Sometimes it is difficult or impossible to distinguish between the influence of drought and of high temperature on fruit setting. In the tomato branch shown in Figure 54 the poor setting of the blossoms in the upper clusters is probably due as much to the one factor as to the other. High temperature is especially injurious if atmospheric humidity is low and there is considerable wind. Stigmas and stigmatic secretions are dried before pollination and pollen germination can take place.

In the case of low temperature there is less complication with other factors. Honeybees and other pollinating insects are not active below certain temperatures (55° to 58° F. in the case of the honeybee). Anthers of certain species do not discharge their pollen until a certain minimum temperature is reached. Pollen does not germinate or is slow at low temperatures, and the styles may abscise or the blossoms themselves fall before fertilization can be effected.

NUTRIENT CONDITIONS AND FRUIT SETTING AND DEVELOPMENT

In the chapter on "Growth and Fruitfulness" it was stated that flower-bud initiation depends upon the existence of certain nutritive conditions or ratios, at certain critical seasons, within the buds where such differentiation theoretically is possible, and that the numbers formed depend largely upon the quantity of foods present, particularly carbohydrates. In the early part of this chapter it was brought out that after flower buds have been differentiated, their growth and final development into flowers are likewise conditioned upon the availability of an ample supply of food. Food is likewise required for the setting process and for the growth of the tissues that develop into the fruit and its seeds. If food is available in sufficient quantity, setting and subsequent growth proceed normally. If it is not available, the flower or the developing fruit may cease growing, turn yellow, shrivel, and fall off. Often it is difficult or impossible to tell whether the dropping of certain flowers or partly formed fruits is caused by a lack of food, drought, or some other condition, but the evidence indicates that a limited food supply is one of the most frequent and important causes of premature dropping. Through the proper spacing of plants, their cultivation and fertilization, irrigation, spraying or dusting their leaves to protect them against the attack of insects and fungi, and through other cultural measures the grower can often effect substantial increases in food supply. Through pruning he can limit the number of flowers and fruits between which this food must be divided. Consequently, he has a con-

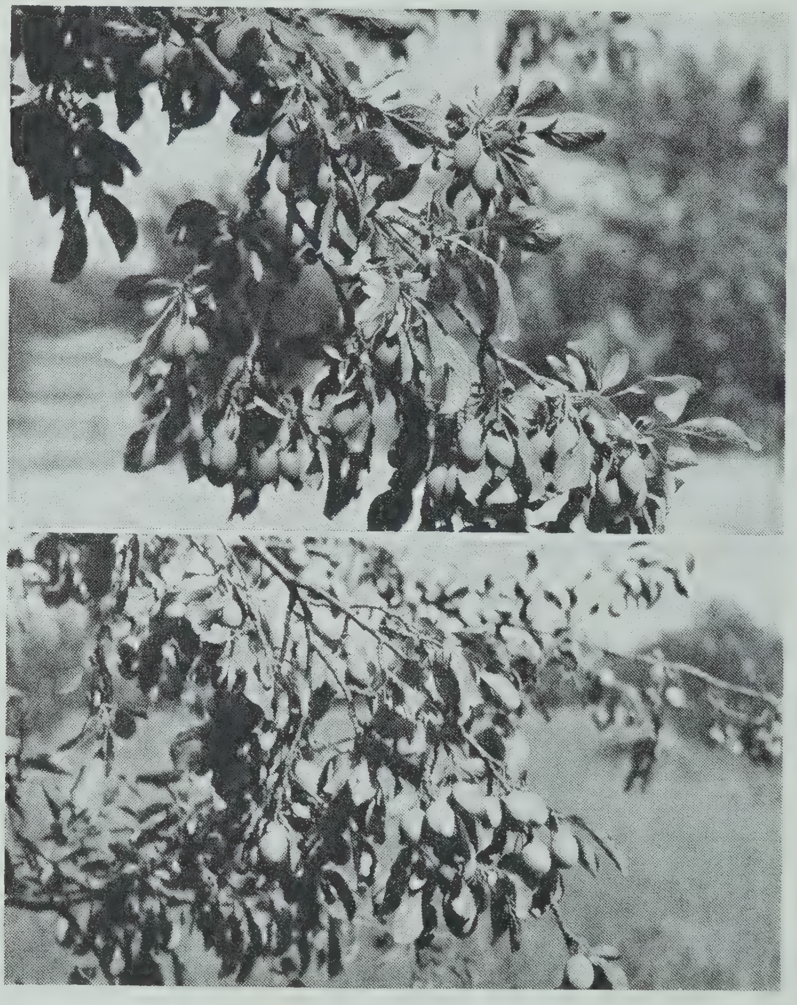


Fig. 130. At the top an unthinned branch of the Grand Duke plum, photographed after the June drop, that had eighty-three partially grown fruits. Below, the same branch just before harvest. It then carried sixty-nine fruits that weighed twenty-seven ounces. Compare with Figure 131.

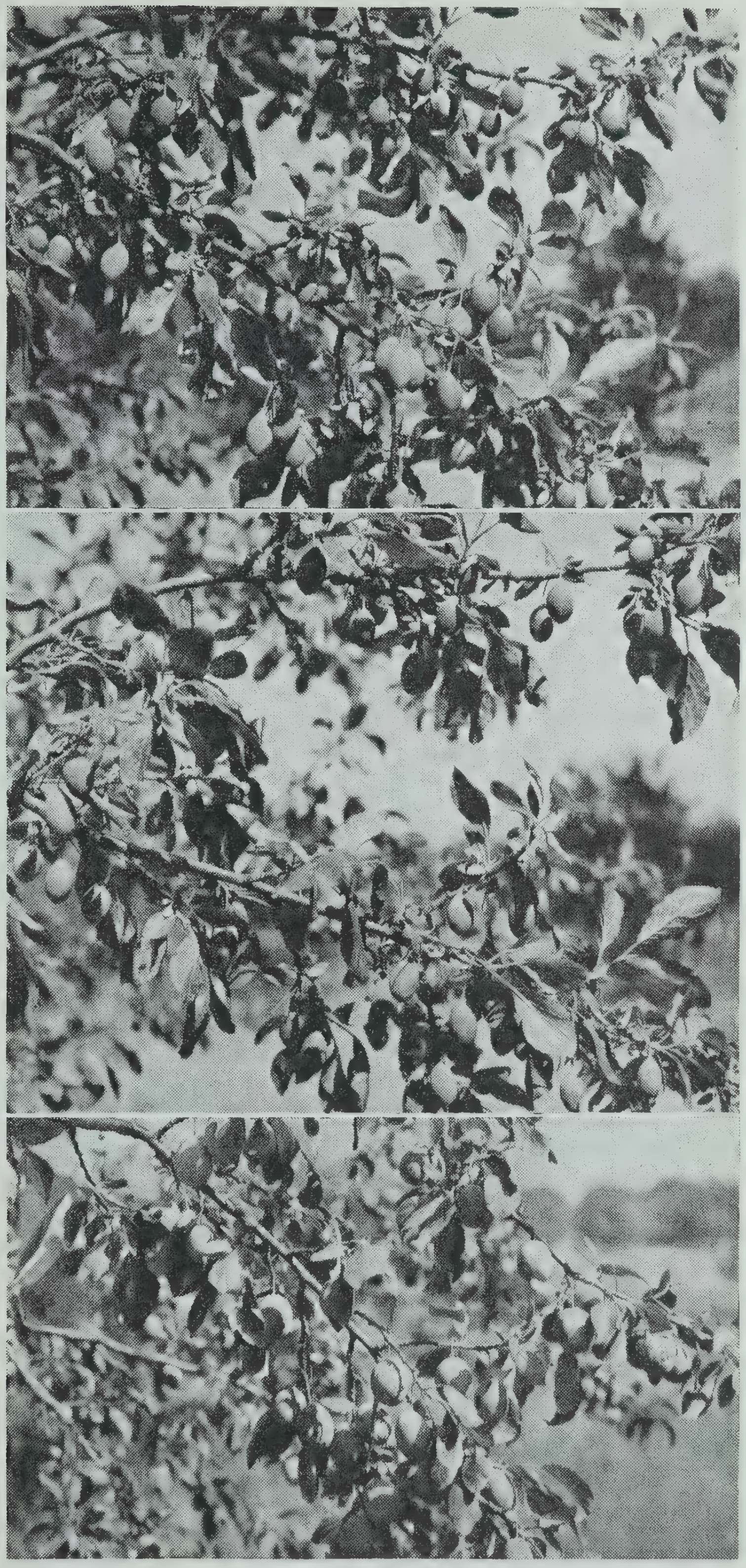


Fig. 131. At the top an unthinned branch of the Grand Duke plum, photographed after the June drop, that had seventy-seven partially grown fruits. Immediately after the photograph was taken, thirty-three fruits were removed, as shown in the center. Below, the same branch just before harvest. Forty-one fruits remained that weighed 33.5 ounces. Compare with Figure 130.

siderable degree of control over the setting and subsequent growth processes, as they are influenced by food supply.

Just as disbudding is a means of reducing the total number of flowers between which the available moisture, nutrient, and food supply must be divided and results in larger size and more perfect development on the part of those that remain, so the thinning of the partially grown fruits reduces the competition between those that remain and results in their attaining larger size (see Figures 130 and 131). It is a regular practice in the culture of such fruits as the apple, pear, peach, and plum, in which size of individual fruits is of importance in determining not only their individual value but their value per pound, per box, or per crate. It is much less frequently employed with such kinds as strawberries, currants, blueberries, or grapes whose value does not depend so much on size of the individual fruits as on some of their other characteristics and in which a certain amount of prethinning can be effected by suitable pruning methods. To be most effective, thinning should be done before the developing fruits attain considerable size — for example, before they are a third grown. On the other hand, it is impracticable to thin them before the June drop has effected the thinning that it customarily accomplishes, for otherwise much needless effort would be entailed, and between the early thinning and the subsequent June drop, too large a proportion of the fruits might be removed. The fruits of the vegetable crops are seldom thinned, though because of the premium sometimes paid for large cantaloupes, watermelons, tomatoes, and certain other crops, thinning may be practicable.

SEEDLESS FRUITS

The fruits of certain varieties of the grape, orange, grapefruit, banana, pineapple, persimmon, and a number of other species are characteristically seedless, and in most cases the seedless quality is highly prized and gives the fruit a somewhat greater market value than that of corresponding seed-bearing or seedy kinds. With a few exceptions, seedlessness is a varietal characteristic, the tendency toward which has been inherited, or it may be due to some abnormality of flower structure associated with hybrid parentage, that may be perpetuated by vegetative propagation. It is not something that can be influenced in any great degree by cultural treatments.

Though perhaps more properly discussed in connection with the setting process, mention may be made of the use of certain so-called *hormones* or growth-promoting substances on the stigmas or cut styles of the flowers of certain plants. These hormones (naphthalene acetic acid, acetamide, etc.) take the place of pollination so far as fruit setting and development are concerned, but the resulting fruits are seedless (see Figure 132). Besides the scientific interest attached to the results obtained from these rather specific growth stimulants, they may prove of practical value in the culture of certain crops such as greenhouse-grown tomatoes.

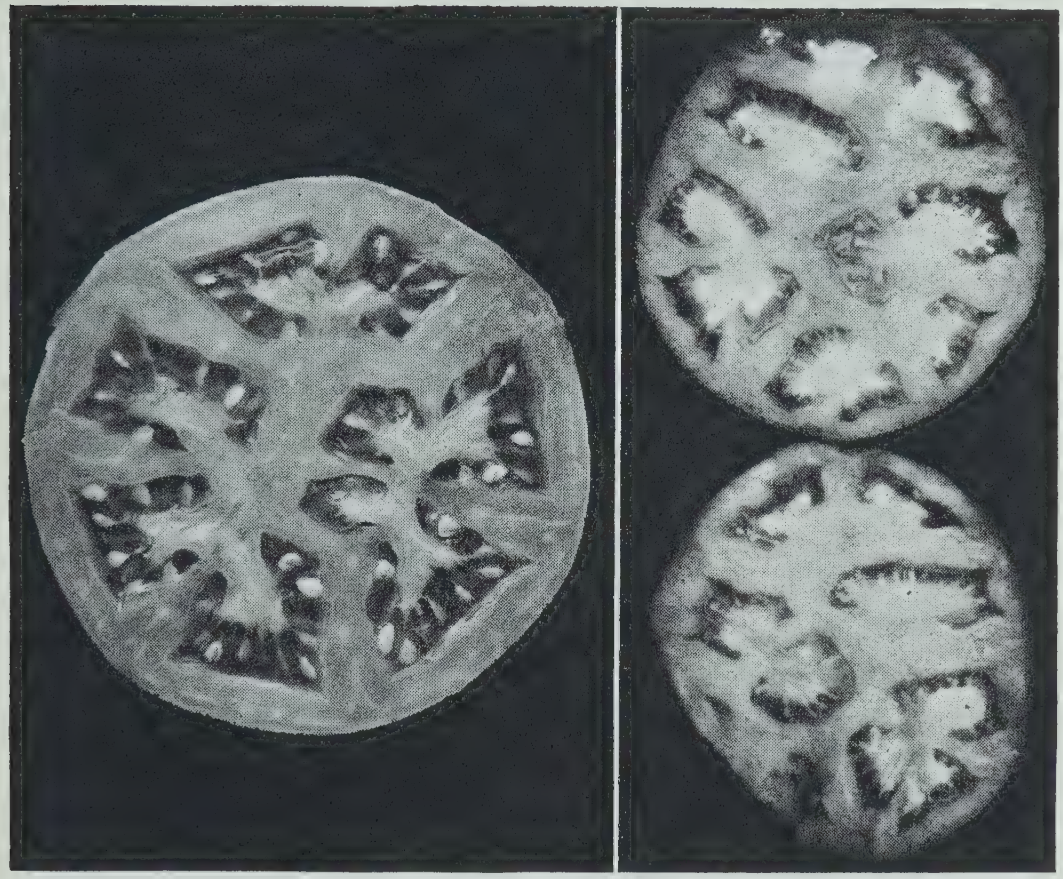


Fig. 132. On the left a cross-section of a normally pollinated, seed-containing tomato; on the right cross-sections of two seedless tomatoes that developed without pollination. The stigmas of their flowers were treated with hormones to stimulate the development of the fruit.

SEED FORMATION

From nature's standpoint seed rather than fruit formation is the objective of the reproductive processes, though fruit development is a necessary antecedent or accompaniment of seed development.

Ordinarily fruit and seeds develop together, and when the fruit is ready for harvest, the seeds have likewise matured, though in many cases curves showing their growth rates at different periods in their development would not be parallel. Abortion of ovules and partially developed seeds often takes place while the fruit is setting and growing — the fruit itself maturing into a few-seeded or even seedless specimen. In many, if not most, of these cases the abortion takes place at such times and under such conditions as are associated with the dropping of fruits, the June drop, in other species or varieties. The farmer or seed-grower says that the seed pods do not "fill."

OVULE ABORTION

Abortion of some of the ovules at the flowering stage or soon thereafter, while others start to enlarge and continue to develop into mature seeds is a regular occurrence in fruits of many species and varieties. Indeed, it is often so regular an occurrence that it may be regarded as normal, and a deviation from this condition to a more complete setting may be considered the abnormal or exception. Thus, almost invariably one of the two ovules in the ovaries of the stone fruits aborts at an early stage, the result being a one-seeded drupe or pit, and it is the exception for all of the ovules of the lima bean to mature into seeds. In many varieties of apples, pears, grapes, and citrus fruits less than half the ovules normally develop into seeds.

In a somewhat different class are those failures that usually come late in the course of development and that may result either in half-grown or entirely abortive embryos within more or less fully formed seed coats — "blanks," the farmer calls them. A very common cause of this late-season abortion is an inadequate food supply, perhaps associated with drought or premature defoliation by insects or fungi or early frost or some other factor that limits photosynthetic activity. It is a condition that often causes large reductions in yield and quality in the nut crops. In grain and forage crops similar environmental conditions lead to the maturing of light or shrunken, as contrasted with heavy or plump, seeds.

In the case of most annual and biennial plants, maturing of the seed crop is promptly followed by the death of the plant. In many cases death apparently results directly from the almost complete exhaustion of the food reserves of the plant through their translocation to and storage in the seeds. In herbaceous perennials and in woody plants, seed production seldom results in such a complete concentration of the food reserves of the plant in its seeds and the consequent exhaustion of supplies in the vegetative tissues, though it sometimes does, and the plant may succumb. In such cases the immediate cause of death may be winterkilling, to which it is especially susceptible in its weakened condition. Retention and functioning of some of their foliage after maturing of their seeds result in a building up of new reserves in roots, crowns, or other vegetative organs and thus provide for a vigorous initial growth the following spring. In herbaceous perennials, such as the peony and iris, in bulbous plants such as the tulip and *Amaryllis*, and in certain woody plants such as the rose, plants in which neither fruits nor seeds are prized, this recuperative process can often be greatly aided by prompt removal of the developing fruits or seed pods immediately after blossoming. This avoids the exhaustion of food supplies due to seed development. In the case of perennial plants grown for their seeds, for example, the walnut, chestnut, almond, and coffee, overbearing should be prevented by pruning or other means; otherwise the resulting exhaustion may so weaken the plant that it may not flower, fruit, and seed again for several years. In this way the tree acquires the very irregular growing and fruiting cycle commonly found in many forest trees.

Some measure of the exhausting influence of seed production, as compared with that of fruit production, is afforded by experience with seedless and seed-bearing varieties of grapefruit when grown side by side on infertile soil in Florida and without the aid of much fertilizer. Though as young nonbearing trees they grow with equal vigor, come into bearing at the same age, and for a while produce crops of the same size, gradually the seedless kinds come to outgrow and to outyield the seed-bearing kinds. This is because of the steady drain of the seeds of the latter on the scanty mineral resources of the soil — a drain that is not made by the even heavier crops of fruit (in the later years) of the seedless kinds.

FLOWERS, FRUITS, AND SEEDS IN PERSPECTIVE

Man's cereal foods — rice, wheat, corn, rye, etc. — are all derived from seeds; this is likewise true of many of his other staple food crops — beans, lentils, nuts, coffee, cocoa, many spices and condiments. In view of the place that these products occupy in the diet (see Chapter I) and the extent to which they and other seeds constitute the food ration of the domestic animals that supply us with our meats, milk, animal fats, and eggs, it is readily seen that directly or indirectly they rank far ahead of fruits and flowers in importance, except, of course, as flower production must precede and fruit production accompany seed production. Furthermore, several of the food products, such as sweet corn, green lima beans, and peas, that are commonly classed and served as vegetables, are in reality seeds, and the nutritional value of many others, for example, string beans and cucumbers, probably lies as much in their seeds as in the fleshy tissues of their immature fruits. Seeds are especially rich in minerals, proteins, oils, and carbohydrates. The fleshy tissues of fruits and edible stems, leaves, roots, and other vegetative structures, besides containing considerable quantities of carbohydrate and smaller amounts of protein, minerals, and oil, are especially rich in acids and vitamins and contribute bulk to the diet. Flowers are seldom eaten, though the flower buds of broccoli and a few other plants are and, from that point of view at least, must be evaluated in an entirely different way. In the sense, however, that flower development and the subsequent setting are necessary antecedents to all fruit and seed production, the flowering process as a whole is of great importance in agriculture.

PROBLEMS

1. List five plants in which flower-bud differentiation is followed promptly by flower development and flowering. List five in which there is a fairly long period of time between the two events.

2. In general, are leaf buds or flower buds the more susceptible to injury by extremes of temperature? Give some examples.

3. What is cleistogamy? How does length of day sometimes influence cleistogamy?

4. What would you expect would be the behavior of a typical "short-day" plant if grown in an equatorial region? Of a "long-day" plant?

5. Is the opening and closing of flowers to be regarded as a response to internal growth processes and conditions or a response to environmental conditions? Explain, and give examples to illustrate and prove your answer.

6. Would you expect the weight or compactness of a bunch of grapes to be the more influenced by nutritive conditions within the plant at the time of flower-bud differentiation and development? Explain.

7. With which plant — sweet peas or carnations — would you think disbudding to be the more practicable? Why?

8. Would you expect the keeping quality of greenhouse-grown double flowers to be better or poorer than that of greenhouse-grown single flowers of the same kind? Explain why. Would the answer be the same for outdoor-grown plants of the same kind? Explain.

9. Do you think it practicable for a florist to base his prices for flowers of different kinds on their keeping quality as cut flowers? Why?

10. Would you think doubling of flowers could take place in the flowers of species that have colored bracts as their showy parts? Explain.

11. What is meant by a normal setting of fruits, and what is the range for normal setting in terms of percentage?

12. Is unisexuality a characteristic of certain flowers or plants or horticultural varieties? Explain.

13. Would you think that there would be more pseudohermaphroditic varieties of orchard fruits or of annual vegetables? Why?

14. Can you name some ornamentals which commonly "set" and mature fruits and seeds, but which would be more satisfactory if they failed to set? Explain why.

15. Which would you think would be the more effective condition for securing cross-fertilization — self-incompatibility or dichogamy? Explain why.

16. Why is self-sterility principally an orchard rather than a field- or garden-crop or ornamental-plant problem?

17. In the strawberry nearly all of the early blossoms set and mature fruit, while most of those that open late fail to set. In the cucumber about the same percentage fails to set early in the season as later. How do you account for this difference?

18. List five vegetable crops, three fruit crops, and five ornamentals with which pollination is never a problem in their ordinary commercial culture. List an equal number in which pollination does constitute more or less of a problem.

19. Is the grower more dependent on nature and less on his own abilities and resources in obtaining a satisfactory "set" with wind-pollinated or insect-pollinated crops? Explain.

20. Trees and shrubs do more or less self-pruning. They likewise do more or less self-thinning of flowers and developing fruits. In what ways are these processes alike, and in what ways are they different in basic causes? In results obtained?

21. From the standpoint of interfering with the fruit-setting process which would be the more dangerous practice — heavy irrigation or deep cultivation during the blossoming and fruit-setting period? Explain.

22. We say that the June drop effects a thinning of the crop. Can we reason from that that thinning would take the place of the June drop? Explain.

23. In what ways are pruning, thinning, and disbudding comparable practices, and in what respects do they differ?

24. Would you expect to find seedlessness of more common occurrence among vegetable crops or among fruit crops? Why?

25. Are ovule abortion and the maturing of light or shrunken seeds due to the same or to different factors? Explain.

26. Would you expect self-sterility to be a more serious problem in raising chrysanthemums in the greenhouse or in raising grapes out of doors? Why?

CHAPTER XVI

PROPAGATION

THE great majority of plants as they grow under natural conditions, and likewise of crop plants, produce seeds freely and are more readily disseminated and propagated by means of seeds than in other ways. Some cultivated varieties, however, have lost their ability (if, indeed, they ever had it) to produce seeds — for example, peppermint (*Mentha piperita*) and some strains of horse-radish (*Radicula armoracia*); a number of cultivated crop varieties, perhaps because of hybrid ancestry or other causes, have never possessed that ability. For instance, the royal walnut, a hybrid between the eastern black (*Juglans nigra*), and the California black (*Juglans hindsii*), produces very few nuts; some varieties of the tangelo, a cross between the tangerine (*Citrus nobilis*) and the pomelo (*Citrus grandis*), though flowering and fruiting freely, produce no seeds; the snowball (*Viburnum opulus roseum*) and hydrangea (*Hydrangea paniculata grandiflora*) produce many flowers, but they are sterile; most varieties of the pineapple (*Ananas sativus*) are seedless, the Madame Salleron variety of *Pelargonium zonale* doesn't even flower, to say nothing of producing seeds. These plants, if they are to survive, must be propagated vegetatively. Furthermore, there are many others, such as the potato, the strawberry, and the blueberry, which can be propagated more economically by means of specialized buds or by cuttings than they can be by seeds. Finally there are many varieties of horticultural plants whose seeds do not reproduce the distinctive characteristics for which they are valued; these too must be propagated vegetatively if their identities are to be perpetuated.

SEMINAL OR SEED PROPAGATION

A *seed* has been defined as "a young plant, packed and ready for transport to wherever it may be wanted to start growing." It is also defined as a "fertilized, ripened ovule." Anatomically it is an embryo plant consisting of a rudimentary stem and root, together with a supply of food sufficient for establishing the plant in a new location, and all encased in a protective coat.

SEED FORMATION AND MATURITY

The seed develops along with the fruit and usually reaches full size and maturity when the fruit ripens. In the case of most dry fruits of noncrop plants their dehiscence or dropping releases the seeds, whereupon they are ready for dissemination by natural agencies. In the case of crop plants harvesting usually precedes the dehiscence stage by a short period so as to prevent loss, but it is delayed as long as possible so that the seeds may become as well dried out as possible. Experience shows that with most so-called *dry* seeds water content must be reduced to less than 12 to 14 per cent if they are to keep well in storage. Most of the drying naturally takes place during the later stages of the maturing process. Indeed, seed ripening is largely a drying process. If harvesting is done before the seeds are thoroughly ripened on the plant or in the pod, they must be given a chance to complete their ripening and drying (as in the shock or stack), or they must be artificially dried before storage. Otherwise they are subject to molding, heating, and premature loss of vitality. One of the principal reasons for the production of such a large percentage of flower and vegetable seeds in some of the drier sections of California, Idaho, and other western states is that climate there is especially favorable for the seed-curing process just prior to, during, and after harvest.

SEED STORAGE

As implied in the preceding paragraph, dry seeds should be stored in a dry place. When exposed to a damp atmosphere, even after thorough drying, seeds take up moisture and become subject to the same rapid deterioration as they would have been had they never been properly dried. The better seed houses provide a special type of air conditioning for their storage rooms.

Seeds of most plants retain their vitality longer when stored at a relatively low than at a high temperature. It is not necessary to store them at temperatures below freezing or even at temperatures closely approaching the freezing point. A temperature of 40° to 45° F., however, is far preferable to one 15° or 25° higher.

The injurious effects of high temperatures are much greater if the moisture content of the seed is relatively high than if it is low.

Thorough aeration of seed in storage to remove the products of respiration and to reduce the danger of molding, is desirable, especially if storage temperature is rather high or if the seed itself is not well dried out. Aeration is accomplished in the case of seeds stored in large quantities by "elevating" them — that is, by mechanically lifting them to the top of a high storage building and then letting or forcing them to spread or fan out as they drop again to the bottom or floor.

There is another class of seeds, in the main those that are borne in soft or fleshy fruits, that requires very different storage conditions. If thoroughly dried following maturity and harvesting, they rather promptly lose their vitality, or else the length of time that they retain it is greatly shortened. Here belong the seeds of most of the so-called stone fruits (peach, cherry, plum, apricot, etc.), many of the nuts (walnut, pecan, and chestnut, etc.), many of the berries (strawberry, raspberry, and blueberry), and others. Under natural conditions the seeds of these plants either are kept from drying out while still surrounded by the fleshy tissues of the fruit, even after the latter decay, or they pass through the digestive tract of animals that eat the fruits and then are protected from desiccation by the animal excreta in which they are embedded. Seeds of many species lie on the forest floor covered by leaves and other debris, where they are kept moist and are likewise exposed to the softening and disintegrating action of acids and other products of decomposition of softer plant tissues. Kept from drying in these or other ways, they retain their vitality a long time.

Moist storage conditions are provided artificially by *stratification* and then storage in a place where their stratification medium does not dry out. Stratification consists in mixing them with sand or in placing them in thin layers, alternating with layers of sand or some other medium that is good at retaining moisture and at the same time permits thorough aeration. Boxes or other containers filled with such mixtures or alternating layers of sand and seeds are usually placed outdoors where they are fully exposed to successive periods of rain or snow and fair weather, to freezing and thawing, and to whatever other variations may occur, or they may be placed in cold storage. Where large quantities of such seed are used by nurserymen, gravel or sand banks are sometimes utilized for stratification and storage. In the case of certain kinds, for example, some of the nuts, alternate freezing and thawing may help crack the stones and thus aid in later germination.

The impression should not be left, however, that the seeds of *all* fleshy fruits should be stratified and then stored where they will remain moist and that *all* seeds maturing in dry fruits should be first thoroughly dried and then stored in a dry place. This is a rule to which there are many exceptions. For instance, seeds of such fleshy fruits as those of the tomato, eggplant, and watermelon should be thoroughly dried and then held in dry storage; those of the honey locust (*Gleditsia triacanthos*) and Kentucky coffee tree (*Gymnocladus dioica*) maturing in dry legumes, should be stratified.

AFTER-RIPENING AND PREGERMINATION TREATMENTS

The seeds of a great many, if not most, species germinate promptly when placed under conditions favorable for that process, even immediately after they have been harvested and cured. Those of some species do not even require curing. Thus, wheat and some of the other grains will sprout "in the shock" when warm, rainy weather immediately follows harvesting. Seeds of some plants, for example, the avocado (*Persea gratissima*) and mangrove (*Avicennia nitida*), sometimes germinate while still within the maturing fruits. These are called *viviparous* seeds. On the other hand, the seeds of many other plants refuse to germinate immediately after harvesting and curing, even though conditions are favorable. They seem to require a certain period of rest or *after-ripening*, as it is sometimes called, before they will respond to the conditions for germination. Just what chemical or physiological changes occur during this period are not well established. Length of the after-ripening period varies greatly with different kinds of seeds and with the conditions to which they are exposed during that period. For example, seeds of the high-bush blueberry (*Vaccinium corymbosum*) will complete their after-ripening process within three or four weeks if stratified and placed in cold storage; they require many months if dried and kept in dry storage.

In an earlier paragraph it was stated that in most plants seed formation proceeds concurrently with the development of the fruit, and seeds mature about the same time that the fruits ripen. Some exceptions are found in important groups of horticultural plants. For instance, the seeds of most orchids are only partly grown when the seed capsules mature and dehisce, and the resulting seedlings are able to complete only the initial stages of the germination process unless they are supplied with food from some outside source. In nature this means that seedlings actually will develop only from the relatively small percentage that find lodgment where organic and mineral foods of the right kinds and in adequate quantities are available. Under cultivation they must be provided from the very start with a suitable nutrient medium. Similarly, the embryos in the seeds of many varieties of the stone fruits cease growing when they attain a quarter or half of the size and degree of development commonly attained by the seeds of other varieties, when the latter have reached maturity. If planted, even under the most favorable conditions for germination, very few will germinate and grow. On the other hand, if the seeds are split open, their embryos carefully removed and placed on suitable nutrient media, they complete their growth in size and finally attain a normal degree of maturity and may be readily germinated. This is perhaps more accurately classified as a pregermination than as an after-ripening process or treatment, because it is accompanied by growth in size and further differentiation instead of just chemical and physiological change.

Possibly to be mentioned here under *after-ripening*, though probably not to be considered as primarily due to a very slow, long-continued after-ripening process, is the behavior of so-called *resistant* seeds, seeds which, though exposed for long periods to conditions favorable for germination, do not respond to those conditions. Such resistance to germination is most commonly shown by seeds with hard, though not necessarily thick and bony, seed coats that are very impervious to water. Some of them may be immersed in water for weeks or months or lie in a moist soil for years without taking up water and swelling. Eventually, however, after being subjected to the influence of humic acid and other softening and corroding factors and processes in the soil, they do take up water and then will germinate.

Seeds of a number of tree species — for example, Kentucky coffee tree (*Gymnocladus dioica*), the black locust (*Robinia pseudoacacia*), the persimmon (*Diospyros kaki* and *D. virginiana*), many weeds, and to a somewhat lesser extent, certain crop plants like alfalfa (*Medicago sativa*) — possess this characteristic. As naturally disseminated from a single seed crop, some will germinate one year, some a year or two later, others still later, the germination extending over a long period of time. This results in a more effective distribution, for if conditions aren't favorable for the establishment of the young seedlings one year, they may be the year following. By certain artificial treatments before planting, many of these resistant seeds can be made to germinate more evenly. These treatments include dipping in strong sulphuric or some other acid or in strong alkali and then rinsing with water. Immersing in boiling water for a few seconds; filing, rasping, or notching the seed coats; and other methods of destroying seed-coat impermeability similarly promote the absorption of water.

VERNALIZATION

A process that is more or less akin to after-ripening but that, strictly, comes after germination has once started, and that usually consists in exposing the germinating seeds to low temperatures for a more or less extended period, is known as *vernalization*. It is essentially a matter of arresting development in germinating seeds. The period may range from several hours to several months, depending on kind of seed and on conditions. Seeds of some species and varieties apparently are uninfluenced by vernalization except as the completion of their germination is delayed by the unfavorable environment. In other species vernalization has a more or less pronounced effect on the subsequent growth of the resulting plants. The general influence is that of materially shortening the time between completion of the germination process and the initiation of the reproductive processes and the development and maturing of flowers, fruits, and seeds. Sometimes this hastening of maturity is accompanied by increased yields. Certain varieties of wheat have been found to be especially subject to vernalization influences, though they have been noted in many other species. Exposure of the germinating seeds of certain species, for example, cotton, to high temperature for short periods has been noted as having a similar vernalizing influence.

Vernalization methods and effects are comparable to certain low temperature influences (cited in Chapter V on "Temperature Relations of Plants") on plants, for example, celery, well along in the seedling stage.

SEED VITALITY AND LONGEVITY

The term *vitality*, as applied to seeds, refers to the presence of life in them. It implies: (*a*) both that certain life processes, such as respiration, are going on, though perhaps at an extremely slow rate (as would be the case in dry seeds stored at a low temperature), and (*b*) that the seed is capable of germinating when placed under suitable conditions. *Longevity* refers to the length of time that seeds will retain their vitality. The seeds of some plants, for example, the avocado (*Persea gratissima*) and cocoanut palm (*Cocos nucifera*), are characteristically short lived. Those of most kinds retain their vitality somewhat longer — two to four years; those of still other kinds, for example, the watermelon and cucumber, are comparatively long lived — ten to fifteen years; and those of a few are known to remain alive for a number of decades if properly stored. However, there are no reliable records to support the claims sometimes made that seeds unearthed from old burial or storage chambers after many centuries have germinated. Longevity of seeds depends not only on kind of plant but is greatly influenced by conditions of storage.

GERMINATION

Germination is the resumption of growth of the embryo and is the process which results in the production of a seedling. The food supplies derived from the parent plant and previously stored in the seed will have been exhausted in the growth of the embryo, and if conditions are favorable, the new plant will be able to obtain water and a supply of mineral nutrients from the soil, manufacture a food supply of its own in its leaves and stems, and lead an independent existence. The last two statements perhaps do not apply strictly to such plants as dodder (*Cuscuta gronovii*) and mistletoe (*Phoradendron flavescens*) that grow as parasites on other plants. Germination includes several distinct steps: (1) the absorption of water and swelling; (2) the digestion, due in part to the physicochemical process of hydration and in part to enzyme action, of the reserve foods stored in the seeds; (3) translocation of these digested foods to the growing points of the embryo; (4) growth of the embryo itself, resulting in: (*a*) breaking of the seed coat, (*b*) anchoring of the plant by means of a root development extensive enough to obtain a supply of water and nutrients, (*c*) production of green leaves (or cladophylls). This may require only a few days in some species, provided conditions are favorable, and weeks or even months in others. If the imbibition of water is considered a part of the germination process, as it indeed is, it may require several or many years in the case of some of the more resistant seeds of certain species.

Germination may be hastened by providing suitable temperatures for the kinds in question and also by providing an abundant supply of water. Temperature control is readily obtained in the greenhouse, hotbed, or cold frame. In the case of seeds planted in the open, about the only temperature control possible is so to time seeding that expected temperatures will be as near as possible to those desired during the germination period. Seeds of warm-season crops will be planted somewhat later than those of cool-season crops. In some instances, for example, in the greenhouse or where intensive gardening areas are provided with overhead irrigation facilities, the seed bed can be watered or sprinkled as often as necessary following planting. It is seldom practicable to do this in the case of field crops, though it is often employed in starting a lawn. However, having the seed bed in a finely pulverized condition and then pressing the soil firmly down over the seed, usually accomplished by means of rolling, results in greatly increasing the number of points of contact between soil and seed, and this increases the rate of water absorption. Firming the seed bed in flats or seed pans in the greenhouse or hotbed is for the same purpose.

Depth of planting is influenced to some extent by kind of seed and the method of germination. For instance, peas and field beans have seeds of about the same size, but the pea seeds are planted deeper than beans because in the case of the latter crop the large fleshy seed leaves or cotyledons are raised above ground in germination while those of the peas are not. Were beans to be planted as deep as are peas, many germinating seedlings would never reach the surface. Some of these differences are brought out in Figures 175 and 176. Within certain rather wide limits, and recognizing a number of exceptions, depth of planting depends principally on size of seed. Seeds that are three sixteenths to a quarter of an inch in diameter ordinarily will be planted from one and one half to two and one half inches deep; those about an eighth of an inch in diameter are planted about a half inch in depth; and very small seeds like those of *Calceolaria* and lobelia (*Lobelia tenuior*) are simply scattered on the surface of the soil and then pressed down more or less to embed them and firm the soil around them. Usually the deeper the seeds are planted, the more uniform will be their moisture supply, and the more difficulty the seedlings will have in reaching the surface. On the other hand, the more shallow they are planted the more subject they are to drying out. The surface drying in flats and seed pans can be greatly reduced by placing a bell jar or pane of glass over them during germination, or by shading them or covering them temporarily with paper or by any one of a number of other means. Surface drying during the early stages of the germination process may not be serious, though it usually retards it. If this occurs a little later while the seedlings are attempting to break through the surface or shortly thereafter, it may result in the death of a considerable number of the seedlings.

VEGETATIVE PROPAGATION

SEPARATION AND DIVISION

Chapter IV on "Specialized Stems and Buds" describes a number of vegetative structures that separate naturally from the parent plant or may be readily separated from it and that are commonly used for the propagation of many plants. Little needs to be added at this point regarding them. They include stolons, runners, crowns, offsets, bulbs and bulblets, rhizomes, tubers, and cormels. These specialized buds or stem structures are generally many times larger than the seeds of the same plants; they contain a much greater store of reserve foods; and consequently when placed under conditions favorable for growth, they are able to produce large strong plants in much less time than would be required from seed.

As with seeds, the specialized buds and stems that are used in the propagation of many plants must undergo an after-ripening or resting period after they have been fully developed before they will vegetate. In view of the fact that, like seeds, their development occurs principally during the latter part of their growing season, and considerable time usually intervenes between the end of one season and the beginning of the next, after-ripening takes place, and the resting period ends naturally, and no further thought needs to be given to it. On the other hand, should these vegetative structures be required for early winter forcing, some special treatment for breaking the rest period, such as etherization or artificial freezing, may be required.

LAYERAGE

Between propagation by means of some of the naturally formed offshoots, just described, and layerage there is no sharp line. When the tip of a black-raspberry (*Rubus occidentalis*) cane bends over and touches the ground, thickens, takes root, and establishes a new plant, we call the structure a *stolon;* when the process is aided or hastened by artificial bending and covering the branch tip with a little soil, we call it *tip layerage.* If a median section of the branch, instead of its tip, is fastened down and covered with soil so that it strikes root, we call it *common layerage.* If the branch is long and flexible, as in a vine, and it is covered at several places so that roots may form at different nodes, we call it *serpentine layerage.* When the shoots are erect and stiff and do not lend themselves to bending and fastening down, and we mound the soil up around their bases so that they may strike root at the base, we call it *mound layerage.* Mound layerage becomes *stool layerage* when the plant is cut back to the ground and forced to throw out a large number of shoots, that is, to form a stool, that in due turn are mounded to promote rooting. If the branches or shoots are so large or arise so far above ground that neither bending them down nor mounding up around them is practicable, a pot of soil or a ball of moss or similar material may be fastened about them at the desired points; in due course of time rooting will take place in the artificially placed medium. This is called *air layerage.* In all these forms of layerage the rooted branch is removed from the parent plant when enough roots have formed to enable it to lead an independent existence.

The black raspberry and Logan blackberry (*Rubus loganbaccus*) are examples of fruits commonly propagated by means of stolons and tip layerage; the gooseberry (*Ribes grossularia*) and currant (*Ribes rubrum*) and most of the so-called *Malling* apple stocks are often propagated by means of mound layerage; grapes and a number of ornamental vines may be propagated by means of serpentine layerage; air layerage is in common use in the greenhouse for the propagation of such plants as the India rubber (*Ficus elastica*), the crotons (*Codiaeum variegatum*), and many others. With these ornamentals it is often as useful in eliminating the unattractive bare stems of plants that have become long and "leggy" (Figure 133) as it is in their actual increase in numbers.

In general, layerage is used in the propagation of plants that do not come true to type when grown from seeds, that do not form offshoots or specialized buds which may be used for their increase, that do not graft readily, and, more especially, whose stems or leaves do not root readily when made into cuttings. Nurserymen and florists prefer to propagate by means of cuttage or graftage rather than layerage if they can succeed in getting a reasonable percentage of the cuttings or grafts to grow, for it takes less time, space, and plant material. It is a method that is very useful, however, as a last resort with kinds that do not respond to the other more economical methods. It is also very useful for the amateur who may be inexperienced in the handling of cuttings that require special care and to whom reasonable certainty as to results is more important than time, space, or the maximum utilization of plant materials.

Rooting of layered branches is promoted by surrounding them with a medium that is porous and well aerated but that at the same time retains a large amount of moisture, even under desiccating influences.

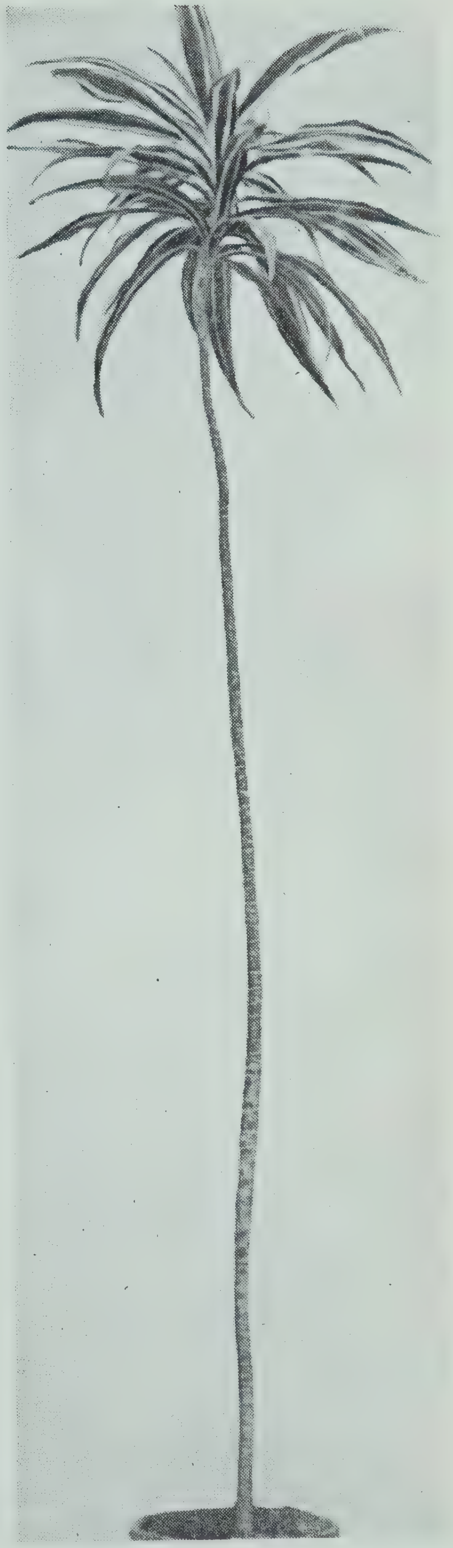


Fig. 133. A tall "leggy" plant of *Dracaena terminalis*. Air layerage is employed to develop roots just below the point of attachment of its lower leaves. Then the top is cut away from its former root system, and a new short-stemmed plant obtained.

A loose, porous sandy loam, well supplied with organic matter, is preferable to sand or clay for tip, common, serpentine, and mound layerage; sphagnum moss and peat are ideal for air layerage. Rooting may also be promoted by notching, girdling, or tightly binding the branches just below nodes that are covered by the rooting medium. The interference caused by such obstructions to the downward translocation of food supplies in the phloem results in their accumulation in the region where roots are wanted, a condition favorable to both callus and root formation.

Tubering and *stumping*, special forms of mound layering, or more accurately the mound layering of more or less specialized, etiolated shoots, has been described elsewhere (see Chapter III).

PROPAGATION BY MEANS OF CUTTINGS

CUTTAGE DEFINED

If no sharp line can be drawn between propagation by means of separation and division on the one hand and by means of layerage on the other, it is likewise impossible to draw a distinct line between separation or division and cuttage or a distinct line between layerage and cuttage. At least the division line is rather arbitrary. If a number of suckers develops from the root of a red raspberry or a blackberry plant and then the root is dug and divided into a number of pieces, each having one or more suckers, and they in turn are planted in the nursery row or in the field, we classify it as propagation by *division;* if we dig the root before any suckers have been formed, cut it into pieces, and plant them in the nursery row or field where in due time they develop sprouts, we classify the method of propagation as *cuttage.* If the prostrate stem of some species of grass or of a vine, such as the popular English ivy (*Hedera helix*) becomes rooted at successive nodes where they come in contact with the soil, it can be cut or divided into as many pieces as there are rooted nodes, and each one used to start a new plant. This is a form of serpentine layerage. If the stem is first cut into pieces, and then the pieces are planted where they can and do form both roots and shoots, thus establishing new plants, it is propagation by means of cuttage.

Cuttage propagation generally implies that roots are formed *only after* stem, root, or leaf cuttings have been made. The stems of many plants, however, form aerial roots freely in a damp atmosphere, roots that may never be able to reach the soil and that subsequently dry out and are lost. If stem cuttings with roots already formed are made of these plants and planted in a suitable medium and under suitable conditions, growth proceeds at once. This would be classified as cuttage, though it differs from air layerage only in the fact that the roots were formed without first providing for them a special medium in which to grow.

At first thought layerage might be classified as a natural, and cuttage as more or less of an artificial, method of propagation. It is true that most cuttings are made by man, but some plants naturally reproduce and spread to new ground by means of cuttings. For instance, many of the twigs of the so-called "crack" willows (*Salix fragilis*) break or snap off from the larger branches under the action of wind or the weight of birds lighting on them or through other agencies and, upon falling or being carried to a favorable location, strike root and establish new plants. The thick heavy branches of certain species, for example, *Stapelia glabriflora* (Figure 134), or the lighter globose or ovoid branches of many cacti, for example, the *Neomammillaria prolifera* shown in Figure 135, are so loosely attached to the parent stems that in due time they break away from sheer weight, fall to the ground, put out roots, and thus become established as new plants. Cuttage is thus seen to be just as natural a means of propagation as layerage or propagation by means of offsets or tubers.

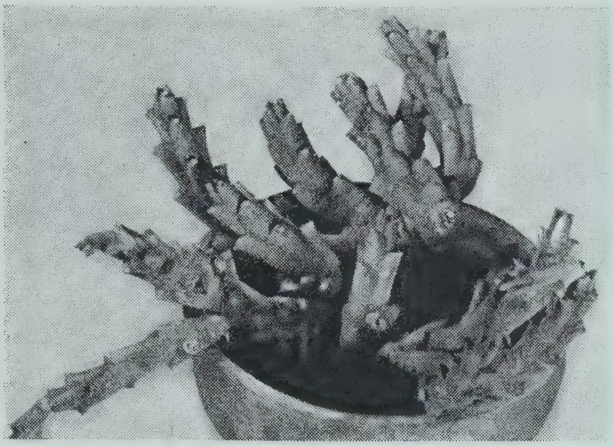


FIG. 134. A potted plant of *Stapelia glabriflora*, part of whose branches have broken off from the main stem, because of their weight and the slender connection that they had with it. Note that they have taken root. This is propagation by means of natural stem cuttings.

STEM CUTTINGS

Theoretically, it is possible to propagate any plant by means of stem cuttings. This, however, is so difficult with some kinds as to make it impracticable. Thus, it has been almost impossible, even with the aid of any of the so-called *hormones* or growth-promoting substances to get cuttings of the oaks, hickories, and walnuts to strike root. Sometimes they callus freely, but there seems to be little relationship between ability to form callus and to initiate roots.

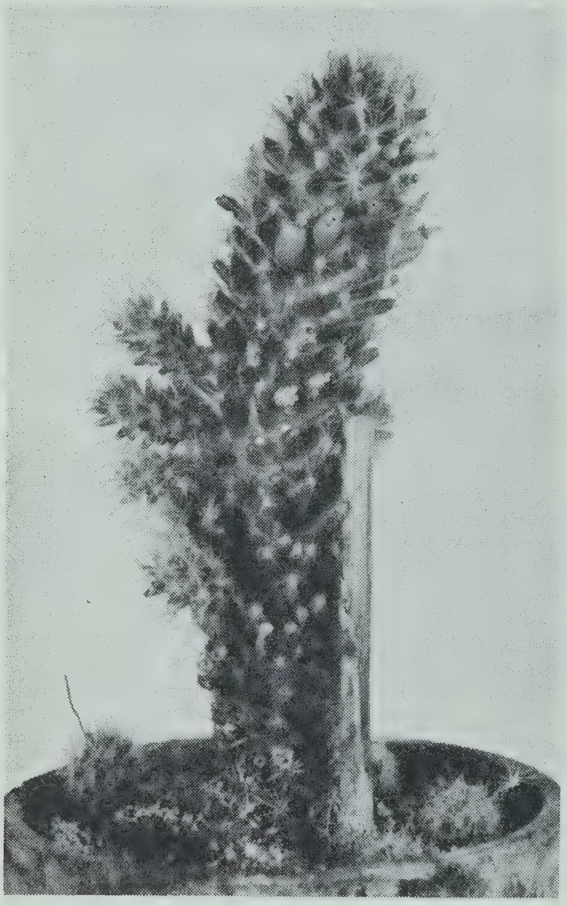


FIG. 135. A potted plant of *Neomammillaria prolifera.* Note that several globose or ovoid branches have become detached and are taking root in the pot. A couple of other branches are attached very loosely to the stem and will soon drop off from their weight. This is propagation by means of natural stem cuttings.

There are many different kinds of stem cuttings. In age they range from the rapidly growing terminals of current-season shoots, the basal ends of which may not be more than two or three weeks old, to branch truncheons such as are sometimes used in the propagation of the olive and that are several inches in diameter and fifteen or twenty years old. Cuttings made from shoots of recent growth that still retain their leaves and that contain little woody tissue are classified as *soft wood.* This generally implies only the terminal several inches of the shoot, though it sometimes includes median or even basal portions provided they are comparatively soft and succulent (Figure 65). Cuttings made from the past season's growth, or older wood that has shed its leaves and that has become well lignified, are classified as *hard wood.* Cuttings of wood that is intermediate in character, both in age and degree of lignification, are classified as *semihard wood* (Figure 136).

Division lines between these three classes of cuttings, however, are entirely arbitrary. Semihard-wood cuttings grade into soft wood on the one hand and hard wood on the other. Cuttings made from terminals of young shoots of the boxwood (*Buxus sempervirens*), for instance, would probably be classified as semihard wood, because even one or two inches back from their tips, considerable lignification would have taken place. Cuttings of shoots that have formed their terminal buds would probably be classed as hard wood, though they still retain their leaves, for their stems are fully lignified. Experience has shown that with many species and varieties soft-wood cuttings give the best results. They are used almost exclusively in the propagation of many herbaceous and semiwoody ornamentals, especially those grown in the greenhouse. Hard-wood cuttings are commonly used in the propagation of grapes, currants, gooseberries, and many ornamentals, such as dogwood (*Cornus stolonifera*) and weigela (*Diervilla*). Semihard-wood cuttings are commonly employed in the propagation of the highbush blueberry (*Vaccinium corymbosum*), many varieties of the rose, many of the evergreens, both coniferous and broadleaved, and many ornamental shrubs and vines. As a

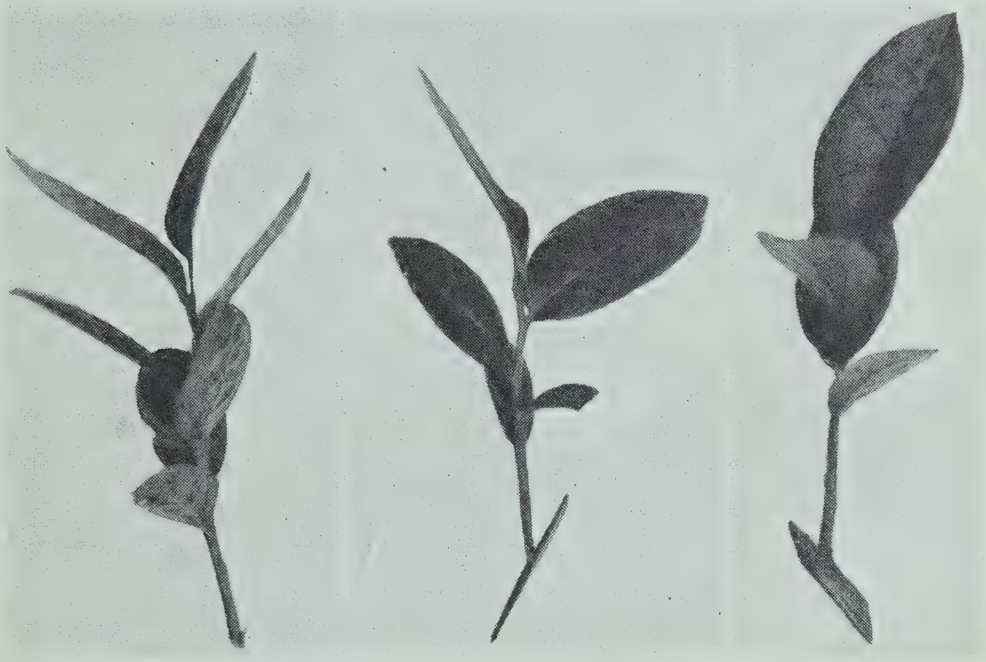


Fig. 136. Semihard-wood cuttings. The one on the left is an ordinary terminal-shoot cutting; the one in the center is a heel cutting and the one on the right is a mallet cutting. If the stems are very slender, the heel and mallet cuttings often root better than the ordinary terminal type.

rule soft-wood cuttings require the least time (two to six weeks with most kinds) in which to root; semihard-wood cuttings require considerably longer (five to twenty-five weeks), while hard-wood cuttings require still longer (eight to thirty-six weeks).

Though cuttings of all these kinds may be made at any season of the year, hard-wood cuttings are more commonly made at the beginning of or at least well before the close of the dormant season. They then have a chance to callus and be ready to form roots, if they have not already formed them, at the beginning or during the early part of the growing season. In this way well-grown "one-year-old" plants may be obtained by the end of the first growing season after the cuttings are made. Furthermore, if made at the end of one growing season or anytime during the dormant season, they are more likely to be better supplied with stored foods out of which callus and new roots may be formed than they would be at any time during the growing season. If the making of hard-wood cuttings is postponed until the beginning of the growing season, shoot growth may precede root development and the cuttings fail. Soft-wood cuttings are made at any and all seasons of the year, depending some on the kind of plant and some on the convenience of the propagator. There seldom is a time when the florist's propagating bench does not contain some soft-wood cuttings, just made, half rooted, or ready to be potted.

In Chapter VII on "Light as a Limiting Factor" the essential light and moisture requirements of soft-wood cuttings were briefly discussed. Semihard-wood cuttings should be provided with essentially the same conditions. On the other hand, hard-wood cuttings require no light until after they start to form roots and generally are either completely covered with the rooting medium or placed in it so that only their uppermost buds from which their new shoots arise are level with or project slightly above its surface. Maintenance of high atmospheric humidity is of less importance with hard-wood than with soft-wood and semihard-wood cuttings, but the rooting medium itself should be kept very moist. Some exceptions should be noted to the statement that semihard-wood cuttings should be provided with a moist rooting medium and a humid atmosphere. Among these are the semihard-wood or, perhaps in some cases, soft-wood cuttings of the so-called succulents — cacti, euphorbias, etc. If handled in the same way as ordinary soft- or semihard-wood cuttings, they are very subject to decay. Usual procedure is to lay them on shelves, tables, or benches in a fairly dry place where they will lose some of their moisture from desiccation, and their cut surfaces will cork over or become plugged with tyloses. Then they are placed in a rooting medium that is kept only slightly moist. Treated in this way they root readily, though in many cases rather slowly.

Temperature requirements of soft-wood and semihard-wood cuttings vary in much the same way as do those for the general culture of the plants from which they are taken, though they are somewhat less extreme. Thus, the optimum temperature for the rooting of poinsettia, croton, and euphorbia cuttings is considerably higher than that for carnation, chrysanthemum, and kalanchoë. In general, it is best if an air temperature can be maintained that is somewhat below the optimum for the general culture of the plant, along with a soil temperature somewhat higher than that in which the roots of the plant generally grow, or perhaps even higher than the air temperature to which the above-ground portions of the cuttings are exposed. Such temperature differences tend to hasten callusing and rooting, at the same time checking the growth of buds and leaves and reducing transpiration losses. It is for this reason that "bottom heat" is often provided for propagating beds. A somewhat lower range of temperatures is desirable for most hard-wood cuttings than would be employed for soft-wood or semihard-wood cuttings of the same plants. This is due in part to the fact that, regardless of temperature, rooting takes place much more slowly in hard- than in soft-wood cuttings. If higher temperatures were provided for them, their buds would open and develop shoots and leaves before the formation of roots that could supply the expanding top growth with water.

ROOTING MEDIA FOR CUTTINGS

At least by implication the requirements of a good medium for the cutting bed have been indicated as: (*a*) ability to hold and distribute evenly a large amount of water and (*b*) porosity to permit good aeration. Water is required to keep the cuttings from wilting; aeration must be provided for the respiration that is incident to callus and root formation. To these requirements must be added a third for most soft-wood and semihard-wood cuttings — comparative freedom from fungi and bacteria which might cause damping-off or decay. This is less important with hard-wood cuttings which are less susceptible to decay and for which a sandy loam soil is often used. For the softer cuttings, however, clean, sharp, rather coarse sand is the best all-around and most commonly used medium, though fine gravel, peat, sphagnum moss, and a number of other materials are sometimes employed. For such plants as the rhododendron, azalea, and blueberry that naturally thrive best in a rather sharply acid soil, acid peat is preferable to sand, which is practically neutral. Influence of medium on rooting of blueberry hard-wood cuttings is shown in Figure 137. Cuttings of hydrophytes generally root better in water than in a solid medium, and water may likewise be used in rooting the soft-wood cuttings of many land plants. Better results are obtained with soft than with "hard" water and with aerated than with non-aerated water.

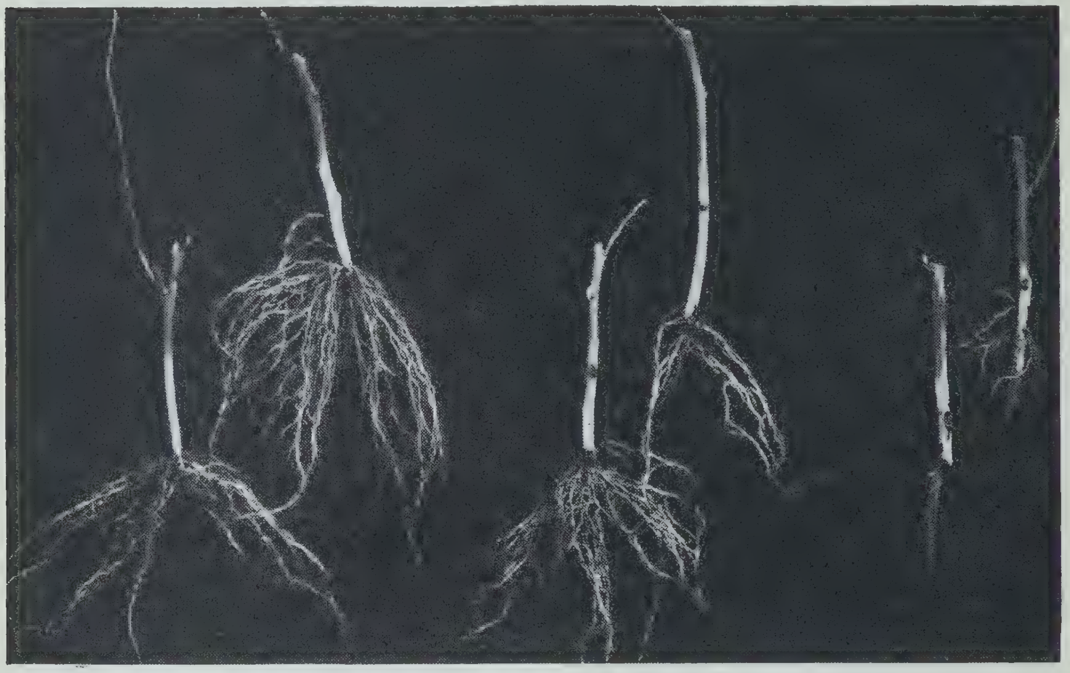


FIG. 137. Blueberry cuttings rooted in acid sphagnum-moss peat at the left, in acid sedge peat in the center, and in acid sand at the right.

ROOT CUTTINGS

In Chapter III on "Plant Structure and Plant Growth" it was stated that adventitious buds are formed on the roots of plants of many kinds. Such plants produce suckers more or less freely and may be propagated by means of them. They may likewise be propagated by means of root cuttings. Such cuttings may be of large or small roots. If they are short cuttings of small roots, the food reserves are limited in quantity; the resulting sprouts will be small; and the new plants will get off to a slow start. On the other hand, use of large roots is wasteful of propagating material. In such plants as the blackberry (*Rubus nigrobaccus*) and horse-radish (*Radicula armoracia*), which are commonly propagated by means of root cuttings and in which a single plant is customarily grown from one cutting, roots three sixteenths to three eighths inch in diameter are generally used and cut into pieces three or four inches in length. Much shorter pieces are sometimes used in propagating the red raspberry. In such plants as the sweet potato (*Ipomoea batatas*) in which the root or root cutting produces a number of sprouts, which, in turn, are broken away from the parent root for planting, much larger roots and root cuttings are used.

In planting root cuttings of such plants as the horse-radish in which the cutting itself becomes a part of what is later harvested, care should be taken to set it in an upright position, with its distal end (the end that originally was farthest from the crown) pointing down. Otherwise, since its shoot will develop from its former proximal end, its roots from its former distal end, the result will be a crooked, misshaped, second-grade product. This is less important with such a plant as the blackberry in which no attention is paid to the shape of its root. It is common practice to place the root cuttings of such plants in the ground in a horizontal position.

Root cuttings are less exacting in their medium requirements than are stem cuttings. They may be grown in sand or other soil, soil being more commonly used than sand. This is because there is less danger of their decaying before new root and shoot formation takes place, in view of the fact that they are already acclimatized and adjusted to soil conditions. Though likewise less exacting in their temperature and moisture requirements than are stem cuttings, root cuttings are subject to temperature and moisture influences. Maximum production of sweet-potato sprouts is obtained only when a fairly high sprouting-bed temperature is provided; consequently, they are generally produced in hotbeds or other structures where temperature can be fairly well controlled.

One of the reasons given for the vegetative propagation of plants is that it is a means of reproducing faithfully the characteristic of the plant from which the offsets, rootstocks, cuttings, or buds are taken. While this is true in a thousand cases out of a thousand and one, or in a million cases out of a million and one, mention should perhaps be made of the fact that some of the variegated varieties of ornamental plants do not "come true" when propagated by means of root cuttings. The variegation disappears, the root-propagated plants reverting to the normal nonvariegated type. Similar reversion occurs in plants propagated from leaf cuttings of some variegated plants.

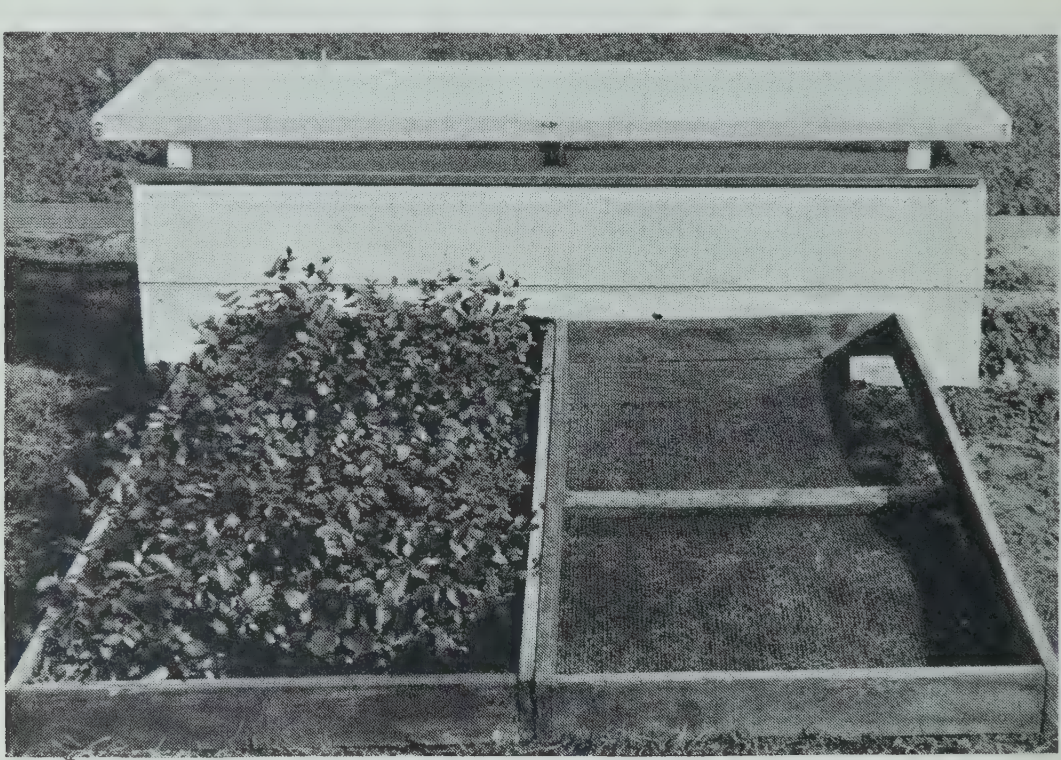


Fig. 138. Photograph showing the construction of an outdoor propagating frame for cuttings. In the foreground on the right is an empty tray, showing its quarter-inch mesh galvanized screen-wire bottom, and on the left a tray containing rooted cuttings. At the rear is a completed frame; the cutting tray shows as a dark band near the top; the light-colored top or cap is a burlap shade tacked to a light wooden frame.

LEAF CUTTINGS

In the discussion of leaves presented in Chapter III mention was made of the fact that the leaves of some plants are able to form adventitious buds. In some kinds, for example, many species of *Bryophyllum*, they are formed regularly without the aid of any special stimulus; in others, for example, certain species of *Kalanchoë* and in the African violet (*Saintpaulia ionantha*), they develop only when the plant or leaf is subjected to certain stimuli or placed under certain conditions. In *Bryophyllum* these buds develop from bits of more or less undifferentiated but nevertheless specialized tissue at the notches along the leaf's margin (Figure 24); in *Begonia* they develop at the point where the petiole joins the leaf blade or along the main veins of the blade, where they branch or perhaps have been injured; in *Gloxinia* they develop at any point on the petiole where it is cut off or injured; in the sword plant (*Sansevieria zeylanica*) they develop along the edges of leaf cuttings that have been placed in a rooting medium much as one would ordinarily place softwood stem cuttings, or they may be formed at still other points in the leaves of other plants (Figure 139). Leaf cuttings provide a very rapid means of propagation for those plants able to form adventitious buds on their leaves, though the young plants are small at first and consequently require more time to attain a certain size than would those grown from stem cuttings of the same plants. The methods of handling leaf cuttings are essentially the same as those for softwood cuttings.

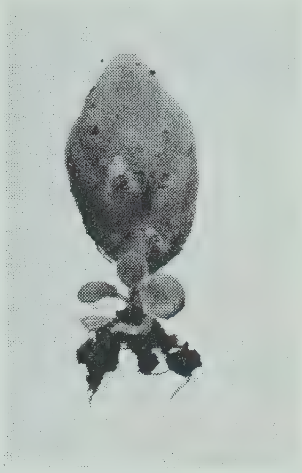


FIG. 139. A leaf cutting of African violet (*Saintpaulia ionantha*). Note that it has developed roots and an adventitious shoot from the base of the petiole.

GRAFTAGE

Grafting may be defined as a method of propagation in which a part (the *cion*) of one plant is so attached or fastened to another plant (the *stock*) that the two will grow together. After uniting, the cion obtains its supply of water and nutrients from or through the stock; the stock in turn gets all or a part of its supply of manufactured foods from or through the cion. Sometimes grafting is employed for purposes other than propagation, and in those instances the definition just given may not strictly apply; nevertheless, it will serve to cover most grafting operations and practices. Some of the other objectives will be brought out in the discussion that follows.

OBJECTIVES

The primary objective in most grafting operations is to propagate or reproduce the plant. Probably upwards of 95 per cent of all grafting is for that purpose. Yet some plants are regularly grafted when propagation by means of cuttings is just as easy and perhaps less expensive. For instance, most rose varieties may be grown readily from semihard-wood cuttings; nevertheless, some varieties are propagated almost exclusively by means of grafting, and many others are largely propagated in that way. In the case of roses this is because some varieties characteristically make rather weak, unthrifty plants when growing on their own roots, but very strong, vigorous plants when growing on certain stocks, for example, the *manettii*. The vines of most grape varieties are propagated readily by means of hard-wood cuttings and many varieties are propagated almost exclusively in that manner. However, the roots of most European (*Vitis vinifera*) varieties are very subject to attack by the grapevine root louse or *Phylloxera* and, when infested, grow very poorly or even succumb to its attacks within a few years. Grafted on roots of certain resistant American species and varieties, for example, *Vitis rupestris* var. *St. George*, they are not troubled by the root louse. In this case grafting effects a substitution of a portion of the plant resistant to a specific insect for one susceptible to that insect. There are literally scores of other plants that are grafted for similar reasons, and in scores more the substitution of a part resistant to some disease for one that is susceptible to it, or a part that is hardy to cold for one that is tender, or a part that is adapted to a particular soil type or condition for one that is not adapted.

Most grafting, at least most nursery grafting, is done because it is the easiest, least expensive method of vegetative propagation, perhaps in some cases less expensive than it would be to propagate by means of seeds. Thus, apples, pears, plums, peaches, apricots, and most other deciduous tree fruits do not propagate readily from cuttings. The same statement applies to the citrus fruits, mango (*Mangifera indica*), avocado (*Persea gratissima*), loquat (*Eriobotrya japonica*), and many other fruits produced by broad-leaved evergreens, and to many ornamentals, such as the holly (*Ilex aquifolium*). Cutting-grown plants of some of their varieties might cost ten times as much as grafted plants, if, indeed, they could be propagated at all.

A somewhat different objective, or group of objectives, is to obtain the advantage of some more or less specific influence that the stock may have on the growth or behavior of the cion, a matter that will be discussed in some detail later in this chapter.

CIONS

The cion is always a portion of the stem or one of its branches of the variety or individual plant that it is desired to propagate. It may be a very small section consisting of a single bud with a bit of the attached bark and wood, or it may consist of a shoot or branch several inches or even a foot in length and possessing many buds. It may be the terminal, median, or basal portion of the current or past season's growth, or it may consist of older wood. Some of the characteristics distinguishing good and poor cion wood were mentioned in Chapter III (also see Figure 25). In most species shoot growth of the current or past season makes better cions than does older wood. In woody plants recent growth of the type that would be classed as suitable for hard-wood cuttings likewise makes good cions. Typical soft wood with leaves, such as is employed for soft-wood cuttings, is seldom used for cion purposes, for herbaceous plants are seldom grafted, and the more mature growth of woody species is preferable to their rapidly growing terminals. Many herbaceous plants can be grafted, however, as for instance the tomato on the potato if there is some special occasion for it. Such combinations are sometimes useful in certain experimental studies. Soft herbaceous cuttings must necessarily be used as cions.

Ordinarily, cions taken from any part of the plant will reproduce the characteristics of the whole plant. In the case of certain species, however, whose branches show a marked dimorphism — for example, coffee (*Coffea arabica*) and the Norfolk Island pine (*Araucaria excelsa*) — care must be taken to obtain cions from certain of the branch types and not from the others. Thus, the coffee tree characteristically produces upright and horizontal branches. Cions taken from the upright or vertical branches produce normal trees with some upright and some horizontal branches; those taken from horizontal branches produce low, spreading, bushlike trees with no vertical branches. Cions taken from an upright branch of the Norfolk Island pine will produce a tree with branches radiating in every direction like the spokes of a wheel; those taken from a flat horizontal branch will produce a tree with branches spread out fanwise in two directions only.

STOCKS

By far the great majority of individuals who purchase grafted nursery trees or shrubs, either fruits or ornamentals, make no specification as to the kind of stocks. Relatively few know even the names of the several kinds of stocks that may have been used by the nurseryman, to say nothing of their respective advantages and disadvantages. Their interest lies in the cion variety. If they get what they want in that respect, they think that is all that is necessary. There are, of course, a limited number of people who know something about the different stocks on which a particular kind of fruit may be propagated, who are aware of the influences that these stocks have on growth and productivity and insist on securing plants propagated on stocks suited to their particular requirements. Such individuals, however, are in the minority and are found principally among the commercial producers of certain fruits. Even within such limitations "stock consciousness," if such it may be called, is usually restricted to certain areas where for some reason certain stocks have notably failed. The fact is that with certain fruits and under certain conditions choice of stocks is fully as important in determining the success of the planting as is choice of cion variety, and it is of considerable importance with most grafted nursery trees that are to be grown under the general run of conditions.

With most species that are propagated by means of graftage, ordinary seedlings of the kind in question can be used as stocks. Thus, pears can be grafted on ordinary pear seedlings, peaches on ordinary peach seedlings, roses on ordinary rose seedlings. In reality experience or experiments have shown that certain special kinds of seedlings are preferable to others or to the general run. Thus, though the cultivated peach varieties can be grafted on peach seedlings of any and every kind, nurserymen have come to use seeds obtained from the semiwild trees that have escaped from cultivation in certain parts of Kentucky and Tennessee in preference to others. They seem to produce more uniform, vigorous, healthy stocks than seeds of most cultivated varieties. Plum varieties of the European group (*Prunus domestica*) can be readily propagated on seedlings of these same varieties, but nurserymen use instead seedlings of the peach or of the myrobalan plum. Better plum trees are produced on both of these stocks than on

European plum stocks, those on the peach roots doing relatively better in light, and those on myrobalan stocks relatively better in heavy soils. The roots of the Mazzard cherry (a special type of *Prunus avium*) are more subject to injury from severe winter cold than are those of the Mahaleb (*Prunus mahaleb*), a wild species that grows in southwestern Europe and that is more closely related to the sour than to the sweet cherry. Consequently Mahaleb stock is preferable if the trees are to be planted in a northern section where winterkilling of roots presents much of a hazard. Scores of other illustrations might be given of the advantages and disadvantages of specific stocks, but enough have been cited to show that anyone who plants grafted trees extensively should acquaint himself with them.

Most stocks are seedlings; a few are propagated vegetatively, mostly by means of layerage or hard-wood cuttings. Vegetatively propagated stocks are somewhat more expensive than those raised from seed, but they are more uniform among themselves, and they produce more uniform plants. Where uniformity is desired in some particular respect or some special quality is desired, they are worth their extra cost. Thus, rooted cuttings or layers of the Northern Spy apple are commonly used as stocks for other apple varieties in New Zealand and Australia in order to secure a marked degree of resistance to the root-louse form of the woolly aphis, which otherwise would prove a serious handicap to apple culture in that part of the world. Apple seedlings in general, and even seedlings of the Northern Spy, do not possess such resistance. Similarly, the so-called *Malling* apple stocks, developed at the East Malling research station in England, are vegetatively propagated and are extensively used to obtain trees of certain much wanted sizes and growth characteristics.

Individual nurserymen, or even individual plant-growers and propagators, could raise their own stocks if they desired to do so. In due course of time, however, the raising of stocks has become a very specialized business, and comparatively few individuals or nurseries produce them for the entire nursery trade.

GRAFTING PRINCIPLES AND GRAFTING METHODS

The basic principles and processes on which the success of the grafting operation depends were explained in Chapter III on "Plant Structure and Plant Growth," where it was stated that without callus formation by both stock and cion there can be no graft union. It follows that monocotyledonous plants whose stems do not have a cambium layer and do not form a callus over their wounds cannot be grafted. Grafting is limited to the dicotyledonous plants and the conifers, both of which have stems with a cambium layer. It also follows that the best cion wood is that which is well stocked with reserve foods from which new callus tissue can be made such as that illustrated in Figure 7, and that the season, temperature, and moisture conditions most favorable for grafting are those most favorable for callus formation. It is for these reasons that most grafting is best performed at the beginning of or during the active growing season — that is, when the cambium is active — rather than during fall or winter when the cambium is inactive, though the plant may still possess its leaves, and photosynthesis and other processes may be going on normally. As just stated, callus formation on the part of both stock and cion is generally at the expense of stored foods rather than the result of currently proceeding photosynthesis; therefore neither the uniting callus tissues nor other parts of the plant require exposure to light (except perhaps in the case of some herbaceous grafting where the cions correspond to soft-wood cuttings.)

There are numerous ways of joining or fitting together stock and cion so that their cambium tissues and the calluses that develop from them meet and press against each other, thus making a union possible. These have been given names, such as *splice*, *tongue*, *saddle*, *cleft*, *inlay*, *side*, *approach*, *bark*, etc., that are more or less descriptive or explanatory of the procedure employed or of the completed operation. Some have come to be used rather generally with certain kinds of plants or with stocks and cions of certain sizes. It may be doubted, however, if any one method can be said to be best even for a single plant.

Regardless of the particular method employed all exposed woody tissue and all cracks or cuts should be covered with some material that will protect both stock and cion from desiccation. Special grafting waxes of many kinds have been used; other materials, such as adhesive tape or friction tape, paraffin, and putty, have been employed with equal success. The essential thing is to protect the tissues from drying out; usually an effort is made to seal the wound and make it airtight and watertight. It should be a material that does not itself penetrate and kill or injure the bark or cambium. As an added precaution against drying out, the whole cion or the cion and the end of the stock may be coated with wax or covered with a bag of paper, cellophane, or other similar material.

Budding is a name applied to a special kind of graftage in which the wood of the stock is not cut at the point where the cion is brought into contact with it. Instead a piece of its bark is removed, and in its place is inserted a piece of the bark of the cion, this cion bark containing a bud, or no bark may be removed from the stock, but an incision made in it in such a manner as to permit a flap to be lifted or pried far enough out or away from the stem for the cion bark, with its bud, to be slipped underneath. The bark flaps of the stock are then pressed and tied down over the inserted cion bud to hold it in place and protect it from desiccation. In the budding operation the cambium or the inner exposed surface of the cion bark is held firmly against the cambium of the stock exposed by lifting a flap of its bark; the callus tissues from the two soon grow together and form a graft union.

Budding must be done at a season when the bark slips readily. It may be done in the early spring, using for cions buds of the preceding season's growth. More commonly it is done in mid or late summer, using for cions buds from the current season's growth. Some species, for example, the peach and most cherries and plums, bud more readily than they graft and consequently have come to be propagated almost exclusively by means of budding. As a rule, budding is less successful than grafting on stocks with rather thick bark. Consequently grafting is generally employed in the top-working of well-established trees, though budding is employed in the nursery propagation of the same trees.

LIMITATIONS OF GRAFTAGE

The statement was made that grafting is limited to dicotyledonous plants and conifers whose stems have a cambium layer. This does not mean, however, that any and every dicotyledonous plant or conifer can be grafted on any and every other dicotyledonous plant or conifer. There are many distinct and, in many cases, extremely narrow limitations to the formation of successful graft unions. Different varieties belonging to the same species can usually be grafted upon each other, and in a great many cases different species belonging to the same genus intergraft freely. Plants that are more distantly related, as a rule, are much less likely to succeed when grafted the one upon the other, though there are some well-known exceptions. Thus, both the apple and pear may be grafted on the mountain ash (*Sorbus americana*), a tree that belongs to a different genus; the quince (*Cydonia vulgaris*) is the commonly used dwarfing stock for the pear. When two varieties or species intergraft readily and make long-lived unions, we say that the two are *congenial;* when they fail to effect a union or make only a short-lived union, we say that they are *uncongenial.*

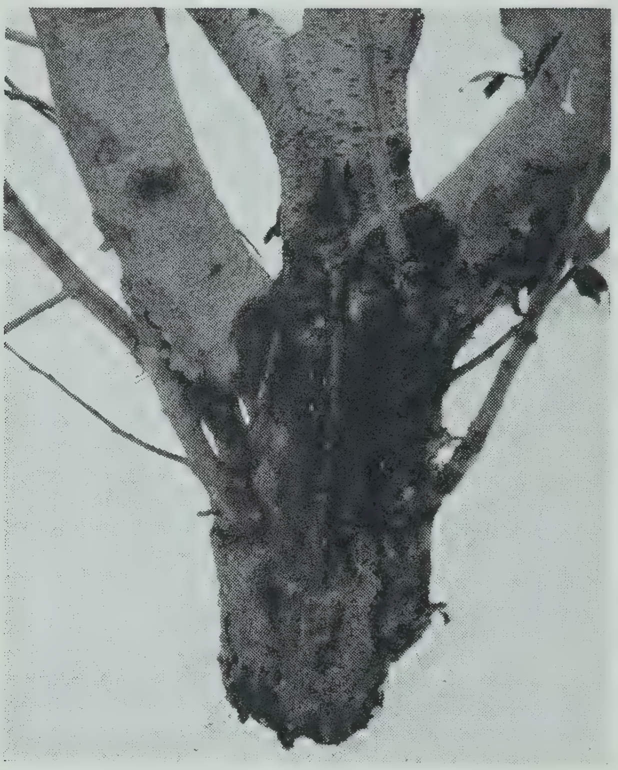


FIG. 140. A girdled peach tree that was bridge grafted. The slender cion in the center of the photograph was a peach shoot and failed to unite. The ones at the sides were plums; they united with the peach and grew well for one year. Then they died. Short life of cions that have made graft unions with a stock is evidence of a lack of congeniality.

Lack of congeniality is indicated by: (*a*) complete failure to unite, (*b*) effecting a union that is short-lived (see Figure 140), and (*c*) making a fairly long-lived union but one which fails to permit sufficient flow of water, nutrient, and food materials for good growth and which often is characterized by considerable proliferation and enlargement at the point of union. As a general rule, varieties and species intergraft more readily than they intercross, though there are some exceptions. There is no way of telling in advance of actual trial which combinations will and which will not be successful.

RECIPROCAL INFLUENCES OF STOCK AND CION

Often the variety or species used as a stock possesses leaf, stem, flower, fruit, or growth characteristics very different from those of the cion, and the question arises as to the influence that the one portion of the plant may have on the other.

In general there is a clear-cut, plainly visible line of demarcation between stock and cion at the graft union. That line marks the boundaries of two types of growth in the grafted plant as distinct from each other as are those of the parent plants growing separately. There is no zone of blended, intermediate, or hybrid tissue and no zone of blended or intermediate characteristics. Above the point of union, leaves, wood, bark, flowers, fruits, and seeds possess the characteristics of the cion variety; below that point they possess those of the stock. And yet the cion may be, often is, influenced by the stock, and in turn the stock is influenced by the cion. Sometimes those influences are profound, though they never result in either of the two parts of the graft losing its identity.

One of the most striking and most important influences of stock on cion is on its rate of growth and stature. Thus, certain stocks have a distinct dwarfing effect on certain cion varieties that may be grafted on them. The pear is dwarfed when grown on quince roots; most varieties of apples are dwarfed when grown on Paradise or Malling No. IX roots; peaches and plums are dwarfed when budded on seedling stocks of the western sand cherry (*Prunus besseyi*). Citrus fruits are dwarfed by trifoliate orange (*Citrus trifoliata*) stock. However, a stock that dwarfs the growth of one cion variety may not have that effect on a different variety. Thus, while the quince (*Cydonia vulgaris*) root dwarfs the pear, it does not dwarf the loquat (*Eriobotrya japonica*), and it actually increases the vigor and size of the hawthorn (*Crataegus glabra*). The dwarfing influence of a certain stock is thus seen to be specific for certain cion varieties, rather than general for all varieties with which it may be compatible, and this same principle applies to other stock-cion influences.

Generally associated with the dwarfing effect of certain stocks (and this is in marked contrast to the dwarfing effect of drought, starvation, shade, and a number of other environmental factors) is earliness of bearing flowers and fruits and often greater productivity throughout the life of the plant. This greater precocity and productivity, as compared with "standards," make dwarf plants so much prized by the amateur. The claim that is sometimes made that the flowers or fruits borne by dwarfs are larger and of better quality than those produced by plants of standard size is open to question.

Though fruits borne by dwarf trees are not any better or any *different* in quality because the trees are dwarf rather than standard in size, quality of fruit is, in many cases, influenced by stock. Such influences are especially pronounced in grapes and citrus fruits. For instance, the acidity of oranges when grown on rough-lemon (*Citrus limonia*) stocks has been found to be from 10 to 15 per cent higher than when grown on sweet-orange (*C. sinensis*) stocks, though the Satsuma tangerine (*C. nobilis*) grown on sweet-orange stock produces coarse, dry, insipid fruit and attains a much higher quality on trifoliate (*C. trifoliata*) stock.

Another very important influence of stock on cion is its productivity — an influence that may be entirely independent of any dwarfing effect. Thus, on certain soils the Campbell Early grapevine is nearly twice as productive when grafted on Gloire or Clinton stocks as when grown on its own roots, its bunches being larger and more compact. The Concord variety as grown in New York has been reported as being twice as productive on *rupestris St. George* roots as on its own. Citrus fruits of most kinds have been much more productive in Florida when grown on rough-lemon than when grown on sour-orange roots.

Among other influences of stock on cion are shape of tree or shrub, season of maturity, and hardiness. The influence on tree shape or form is often very striking, that on season of maturity and hardiness less marked. The Early Richmond cherry when grown on Morello roots is not only dwarfed but the tree assumes a spreading or semi-drooping form, as compared with a roundish upright form when grown on Mahaleb stock. Not to be confused with the influence of stock on hardiness of cion is that of the substitution of a hardy plant part for one that is relatively tender. Thus, the Grimes Golden apple is rather susceptible to winter injury at the crown and in the crotches, and many orchard trees have been lost because of such localized injuries. If a hardy variety is planted and then grafted *in the limb* to Grimes Golden, crown and crotch injury is avoided, and a hardy tree obtained. In this case, however, the hardy stock does not impart its hardiness to the cion variety, but simply replaces the latter where it is most tender.

DOUBLE WORKING

Sometimes there is occasion for grafting a cion variety on a certain stock with which it is more or less incompatible, perhaps in order to obtain the advantage of a root system that is especially well adapted to a certain soil type. Direct grafting would be almost certain to result in failure. Often this problem can be solved by a method known as *double working*, a plan by which some variety with which both stock and cion are compatible is used as an *intermediate* or connecting link between root and top. The stock is first grafted over to the intermediate; then, perhaps a year later, the intermediate is in turn grafted over to the variety that is desired for the top. Perhaps stock and top are separated by only a few inches of the intermediate, but that will be sufficient for adapting the one to the other. Thus, certain pear varieties are

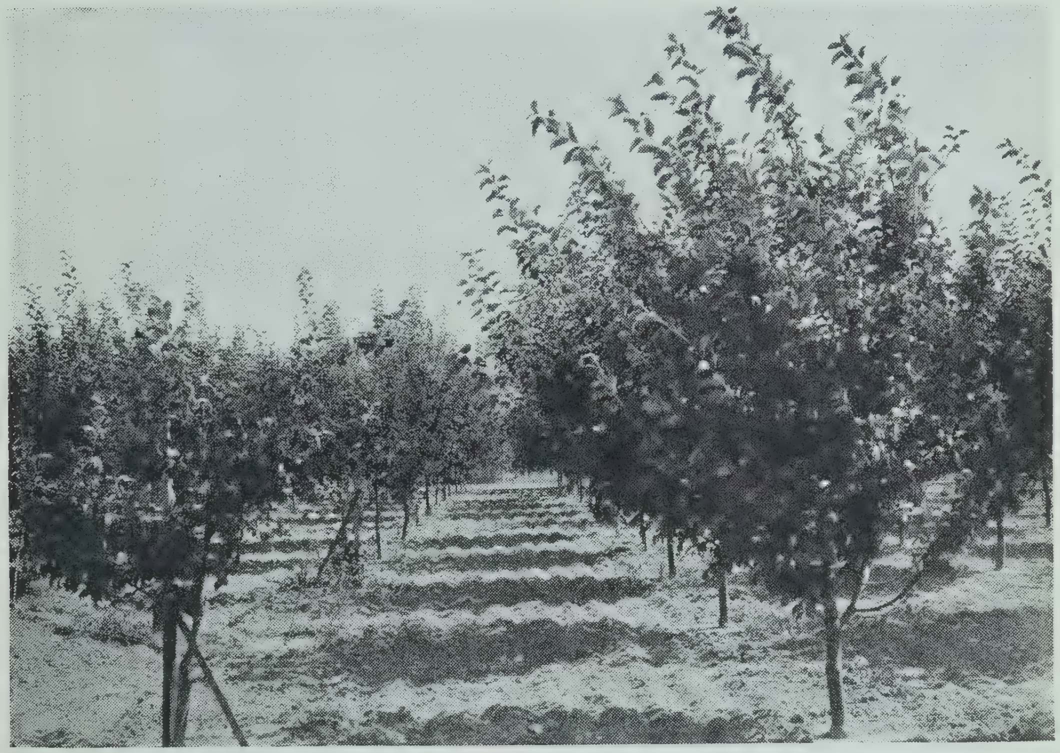


FIG. 141. Two four-year-old McIntosh trees. The stocks under both are vigorous seedlings. The tree on the left, however, has a short "intermediate" section of Malling No. IX, while the one on the right has a short "intermediate" section of Malling No. XII.

incompatible with the quince, and the latter stock cannot be used directly as a dwarfing agent for them. However, it is possible to graft or bud the quince to some pear variety with which it is compatible and then to regraft the first pear variety with the second that it is desired to grow. The second variety is, in turn, dwarfed by the quince root. The tree as a whole is a double-worked tree.

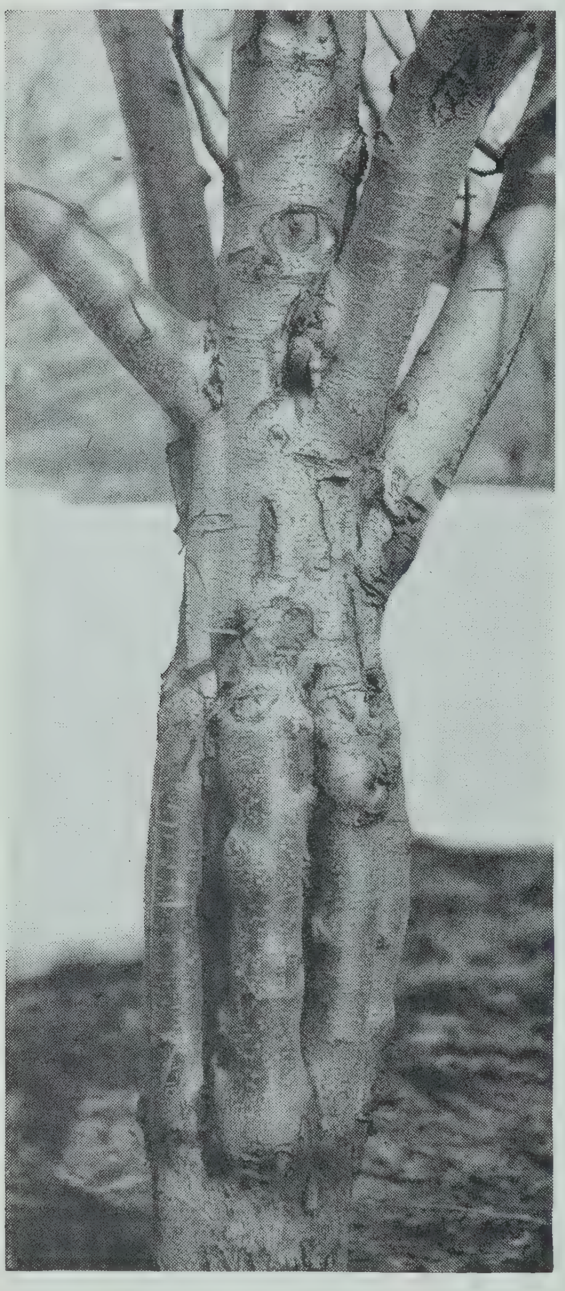


Fig. 142. A successfully bridge-grafted apple tree. The bridges were ten years old when the photograph was taken.

There are many combinations, however, in double working in which the intermediate, rather than the stock, usurps the place of the stock, in influencing the growth of the top. Thus, a dwarfing intermediate (for example, Malling No. IX apple) used either as a stock or as an intermediate, will dwarf the top grafted upon it, regardless of the vigor of the rootstock that may be under it. This is illustrated in Figure 141 showing, on the left and on the right, four-year old tops of the McIntosh apple growing on Malling stocks Numbers IX and XII, respectively.

SOME SPECIAL USES OF GRAFTAGE

Graftage is always thought of as a means of propagating certain plants, and indeed that is its primary purpose. Grafting methods, stocks, and limitations have been described and explained from that standpoint. There are a number of more or less special uses to which graftage is put, however, a few of which will be mentioned here.

Bridge grafting is the name given to a procedure in which the lower end of a cion is trimmed to a narrow wedge and inserted between bark and wood below an injured area on crown, trunk, or limb; its upper end, similarly trimmed, is inserted between bark and wood above the injured area. After both ends of the cion form graft unions with the stock, the cion grows along with the stock both below and above it and forms a bridge across an area over which the bark may have been entirely destroyed. It is a means of saving many thousands of trees, such as is shown in Figure 142, that have been partially or completely girdled by mice, rabbits, winterkilling at the crown, mechanical injury to the trunk, etc. The bridge-grafted tree is essentially a double-worked tree in which the intermediate is not only grafted on the stock but is at the same time grafted under the top instead of the top being grafted on the intermediate a year or so later.

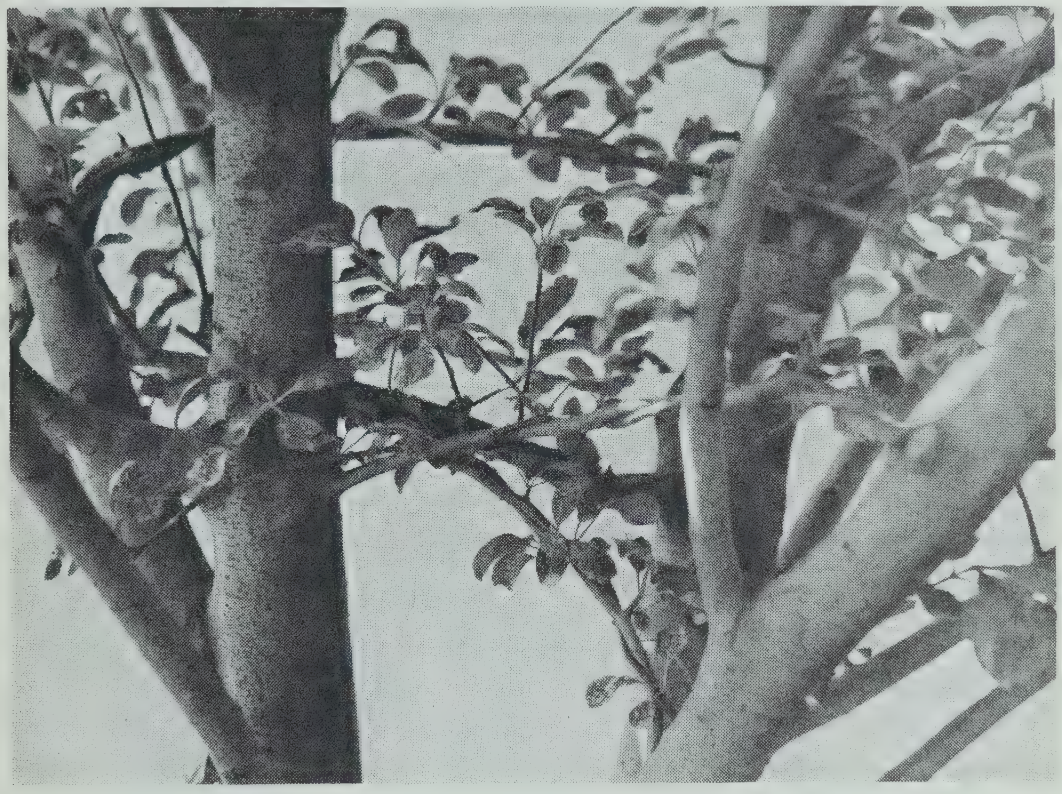


FIG. 143. Small branches from the main scaffold limbs of a tree twisted together so that they can form living braces to prevent splitting.

Another form of bridging, that employs a technique more closely resembling what is termed *approach* grafting or *inarching* when used in the propagation of certain species, is often employed to form living braces between the main limbs of older trees and prevent them from being broken or split apart under the stress of storms or of heavy loads of fruit. They are made by twisting together suitably located shoots or small branches from the two parts of the tree and fastening them so that in due course of time they will grow together. Figure 143 shows several of these bridges "in the making." Such grafts are essentially *natural* grafts, such as are extremely common in the roots of trees and shrubs (see Figure 144) and also found, rather rarely, in their branches.

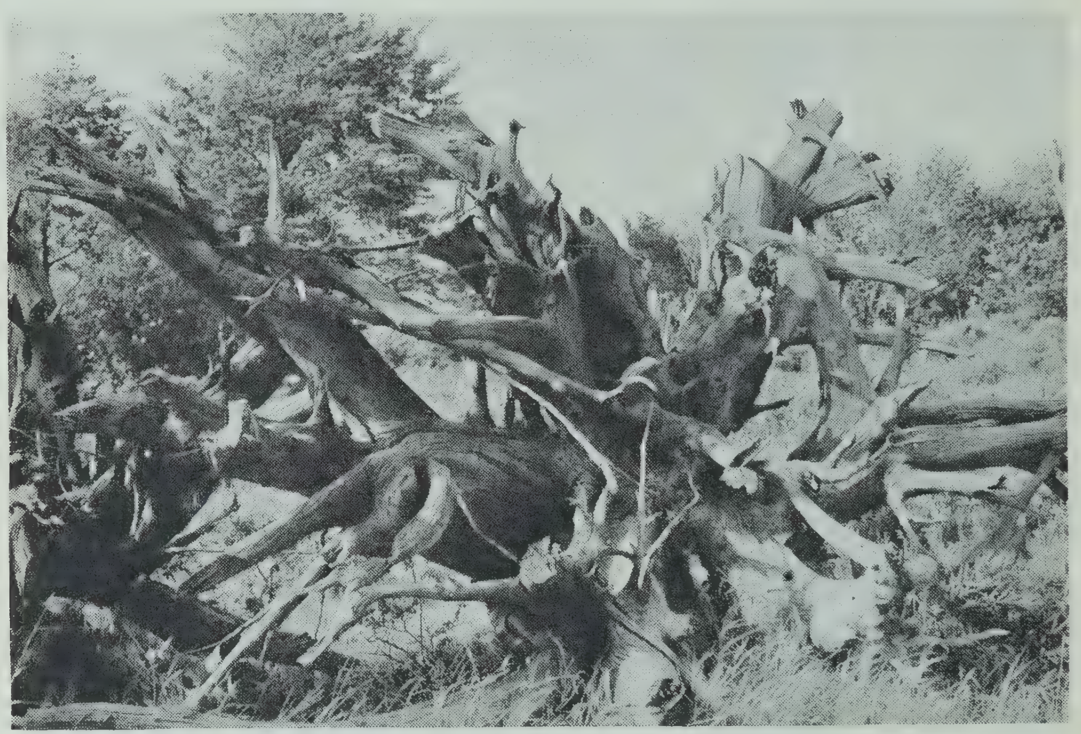


FIG. 144. An old white-pine stump in a stump fence, showing a number of natural root graft unions.

Illustrative of another use of grafting — that of producing a plant of some particular form — is the mulberry tree shown in Figure 145. At intervals of two or three years a series of cions of a weeping variety of this species was set in an ordinary upright growing form at different heights. It took about twelve years to complete the grafting-over process, the topmost cion having been set forty-three years before the photograph was taken. The result is a tree of rather unusual shape. Many of the weeping, globose, or spreading varieties of ornamentals are grafted at various predetermined heights on standard or upright growing forms in order to obtain plants of distinctive outlines or habits of growth. Comparable to these special outdoor forms obtained by grafting are the many indoor curiosities in which such favorite flowering plants as the Christmas cactus (*Zygocactus truncatus*) is grafted on the vinelike *Pereskia aculeata* or the fasciate *Opuntia mamillata cristata* is grafted on the columnar *Hemotocereus serpentinus*. One of these cactus combinations resulting in a rather striking form is shown in Figure 146.

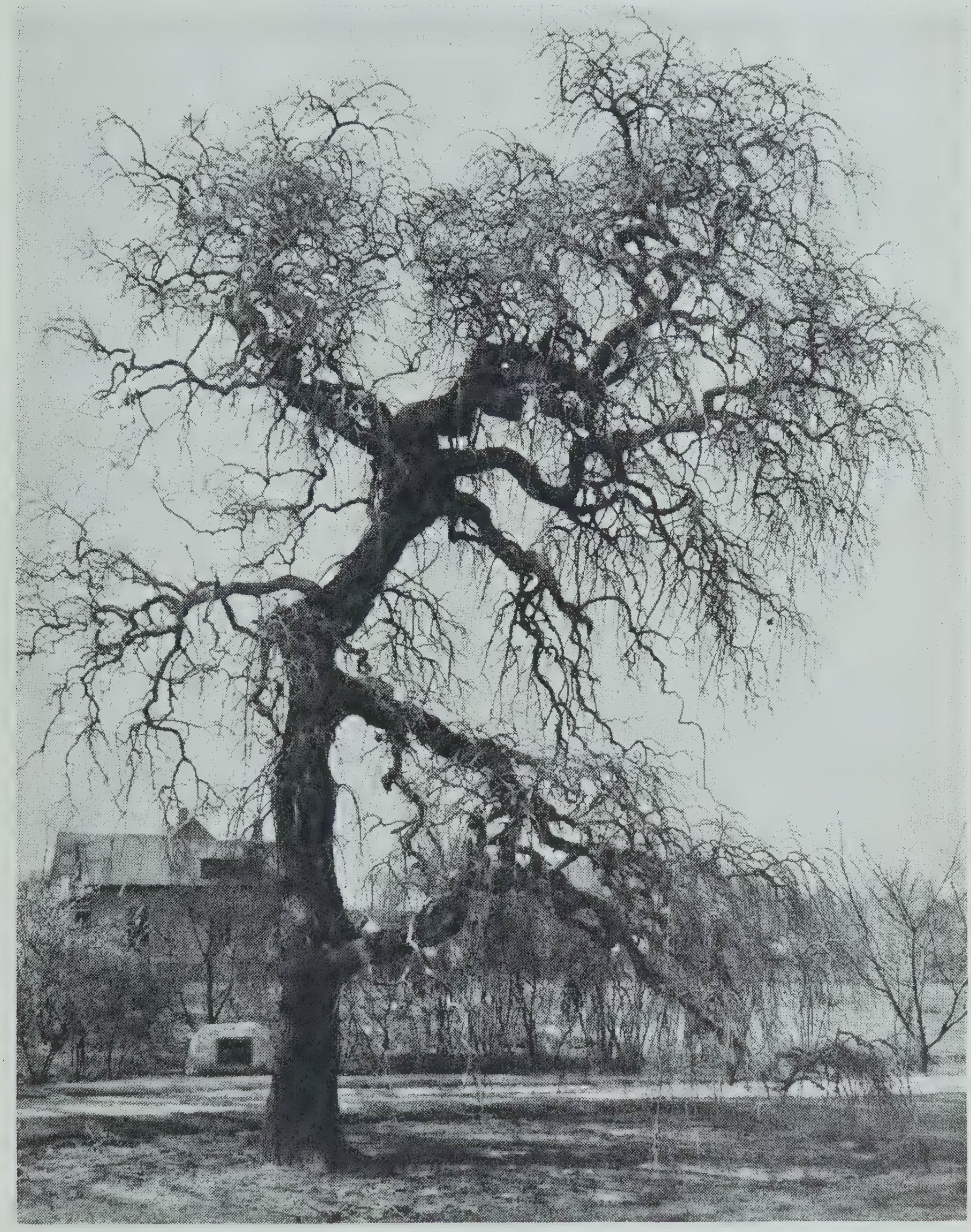


Fig. 145. A weeping mulberry tree in which the grafting over of the standard, upright-growing stock to the weeping form at successive heights was done over a period of about twelve years. The topmost cion was set forty-three years before this photograph was taken.

PLANTS THAT GRAFT WITH DIFFICULTY OR NOT AT ALL

In discussing the objectives of graftage the statement was made that this method of propagation is employed with many plants, such as the apple, pear, peach, orange, lemon, and pecan that are very difficult or almost impossible to grow from cuttings. On the other hand, there are many plants that are very difficult to propagate by either graftage or cuttage — for example, the hickories (*Hicoria*), the oak (*Quercus*), the Norfolk Island pine (*Araucaria excelsa*), and the beech (*Fagus americana*). Seedlings only of such plants are available in the trade, or the limited quantities of vegetatively propagated stock sell at high prices.

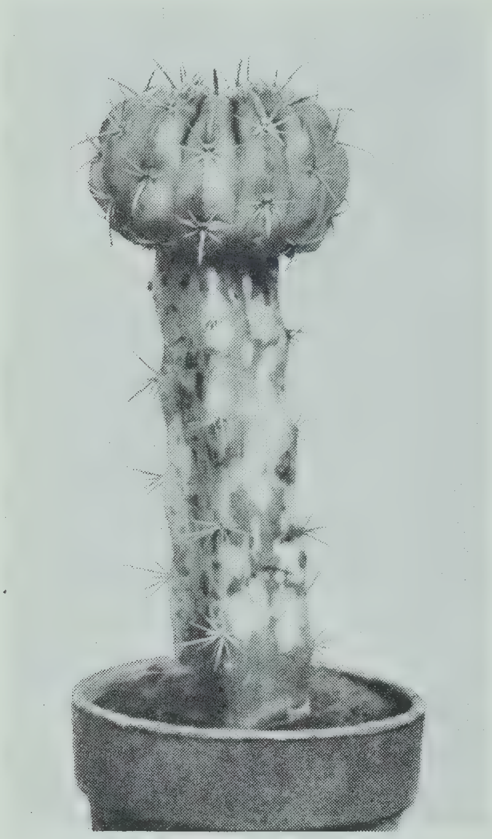


FIG. 146. An interesting combination of cacti — *Homalocephala toxensis* grafted on *Acanthocephala*.

In general, cutting-grown plants are preferable to grafted stock of species or varieties that have a shrublike habit of growth, for they are inclined to sprout from the crown or even from the roots, and then the sprouts, which come from below the graft union, tend to outgrow and replace the cion. One requisite of a good stock is that it shows little tendency to produce suckers.

PROBLEMS

1. Is vegetative propagation to be regarded as an absolute necessity for the horticulturist, or just a convenience? Explain.
2. What is meant by the *after-ripening* of seeds?
3. Would you expect the seeds that require after-ripening to be more or less likely to require stratification or dry storage? Why?
4. **How does the pregermination treatment required by the seeds of certain varieties of cherry resemble and how does it differ from typical so-called *after-ripening* seed treatments?**
5. Can you suggest any method of disproving the claims of a seedsman introducing a variety or seed stock said to have been unearthed from ancient burial places?

6. Which of the several forms of layerage most closely resemble *natural* methods of propagation, and which departs most widely from natural methods of propagation? Explain.

7. Would you recommend that a plant which naturally forms aerial roots freely be propagated by means of layerage, cuttage, or graftage? Why?

8. Would you say that the reasons a higher temperature is generally provided for soft-wood than for hard-wood cuttings of the same plant are the same as, or different from, the reasons that we provide them with a more abundant moisture supply? Explain.

9. Do the same or different factors determine whether plants can be propagated by stem cuttings as by root cuttings? Explain.

10. Cuttings are sometimes made of a single leaf, together with a stem heel or mallet and the accompanying axillary bud. Would you classify these as soft-wood, semihard-wood, hard-wood, or leaf cuttings? Why?

11. How, if at all, do the characteristics of good cion wood differ from those of wood suitable for hard-wood cuttings?

12. Construct a score card by means of which several cion varieties of the same kind of fruit or ornamental could be compared. Construct a score card by means of which different stocks upon which they might be grafted could be compared.

13. Do the same or different basic plant processes determine the time of year at which grafts are set as the time when cuttings are made? Explain.

14. The cions used in budding are of soft wood, but their leaves are removed at the time of setting. Soft-wood cuttings do not have their leaves removed when they are placed in the cutting bed. How do you account for this difference in procedure?

15. In Chapter III the graft union was described as a mechanical dovetail joint between the cells of stock and cion. Is, therefore, failure of certain species to intergraft to be explained as due to mechanical or to other causes? Explain.

16. Distinguish between and give examples of physiological and practical reasons for double working.

17. A tree may be girdled or partly girdled and the top thereby dwarfed, brought into bearing early, and made very productive. Grafting that same variety on certain stocks has similar end results. Would you say that the methods by which the results are brought about are physiologically the same or different? Explain.

18. Wherein lies the difference between a small standard and a "dwarf" tree of the same variety: (*a*) in appearance, as they are purchased from the nursery; (*b*) in their nursery propagation; (*c*) in the way in which they may be expected to grow following planting; (*d*) in the size of the flowers and fruits that they eventually bear?

19. Why are date palms usually propagated by means of offshoots and cocoanut palms by means of seeds, rather than the other way around?

CHAPTER XVII

PLANT PESTS AND THE INJURIES CAUSED BY THEM

IN THE beginning chapter of this book the point was made that literally scores of different plant species are cultivated as edible fruits or vegetables, and many hundreds are grown as ornamentals. In view of the fact that every one of these kinds is subject to the attacks of a few and in some instances to many different species of insects and diseases, it follows that the insect, fungous, and bacterial species that prey upon cultivated plants number among the thousands. For the amateur, or even the commercial, grower to learn to recognize each and every one of the plant symptoms of insect or disease injury is quite out of the question. As a matter of fact, most professional entomologists, plant pathologists, and bacteriologists content themselves with specializing on certain groups, rather than trying to cover the whole insect or disease field. About the best the amateur can do is to learn to distinguish between certain main groups or classes of pests and the disorders to which they give rise and to decide on a treatment that is known to be satisfactory for the group as a whole, hoping that the specific insect or disease and its accompanying disorder will not prove an exception to the rule. With experience, of course, he learns to recognize a few of the most common or most serious pests that attack his plants.

PLANT DISORDERS CLASSIFIED AS TO CAUSE

From the standpoint of causal factors, there are four main groups or classes of plant disorders — (1) those caused by insects, (2) those caused by fungi or bacteria, (3) those due to viruses, and (4) those of a constitutional nature caused by some unfavorable feature of environment, such as drought, starvation, or low temperature. This is a rather arbitrary and not an all-inclusive classification. For instance. there is perhaps as much reason for including virus with fungous and bacterial diseases as there is in considering the fungi and bacteria together. Then there are injuries due to field mice, rabbits, birds, worms, and still other organisms and agencies. Nevertheless, like many other arbitrary classifications in which the division lines are artificial rather than natural, this one serves a useful purpose.

Theoretically at least, injuries due to insects are the most readily recognized of any of the four classes for the reason that the causal agents themselves can be seen and classified. This at least is true of many of them. On the other hand, some insects are of almost microscopic size and may be present in large numbers without actually being seen. Others may work only at night and hide during the day or attack roots or other below-ground organs. Still others, harmless themselves, may be the means of spreading fungous, bacterial, or virus infection and thus serve as important contributing factors for outbreaks or epidemics that otherwise would not be serious. Not only is it generally possible to find the insects themselves, but injuries due to insect attack may usually be recognized as such from the nature of the lesions. For one thing, they are likely to be localized on or in the plant, for example, holes eaten out of leaves (Figure 147), punctures in stem or fruit incident to egg laying or feeding, or curling of foliage and shortening of internodes due to sucking of juices and injection of toxins. There are, of course, exceptions or apparent exceptions, such as the dwarfing of the entire top because of injury to the roots that is not suspected from an examination of the above-ground parts.

Distinct localized lesions that more or less obviously are not due to insect attack may be suspected as due to fungi or bacteria. These may take the form of rusted spots or streaks (Figure 157); of mildewed areas on stems, leaves, or fruits; of decay on fruits; of discolored or desiccated spots or areas of many sizes, shapes, and patterns on or in any organ or tissue of the plant. Less easily identified as due to fungous or bacterial attack, as distinguished from certain disorders of a physiological nature due to unfavorable features of environment, are cases in which some root-invading organism slows down the activity and stunts the entire top. Equally or even more confusing are lesions originally caused by insects and then invaded by fungi and bacteria.

Symptoms of the so-called *virus* diseases more closely resemble those of certain physiological disorders caused by unfavorable conditions of environment than they do those caused by fungi, and bacteria or insect attack, in that the whole plant is generally affected. It may be much stunted; its leaves may become curled or twisted or mottled with yellow; or its vegetative organs may appear more or less normal, but all of its flowers may be deformed or its fruits insipid. Some of the common names used to designate these disorders, such as *mosaic*, *stunt*, *ring spot*, *yellow dwarf*, and *little leaf*, are more or less descriptive of them. The fact that virus diseases usually infect only certain plants in the row or area, leaving others standing among them that are perfectly healthy and normal in appearance while fungi and bacteria, and even insects, are likely to be more evenly and universally distributed throughout a group of plants or throughout an area, is often a means of helping distinguish between the two groups of disorders.

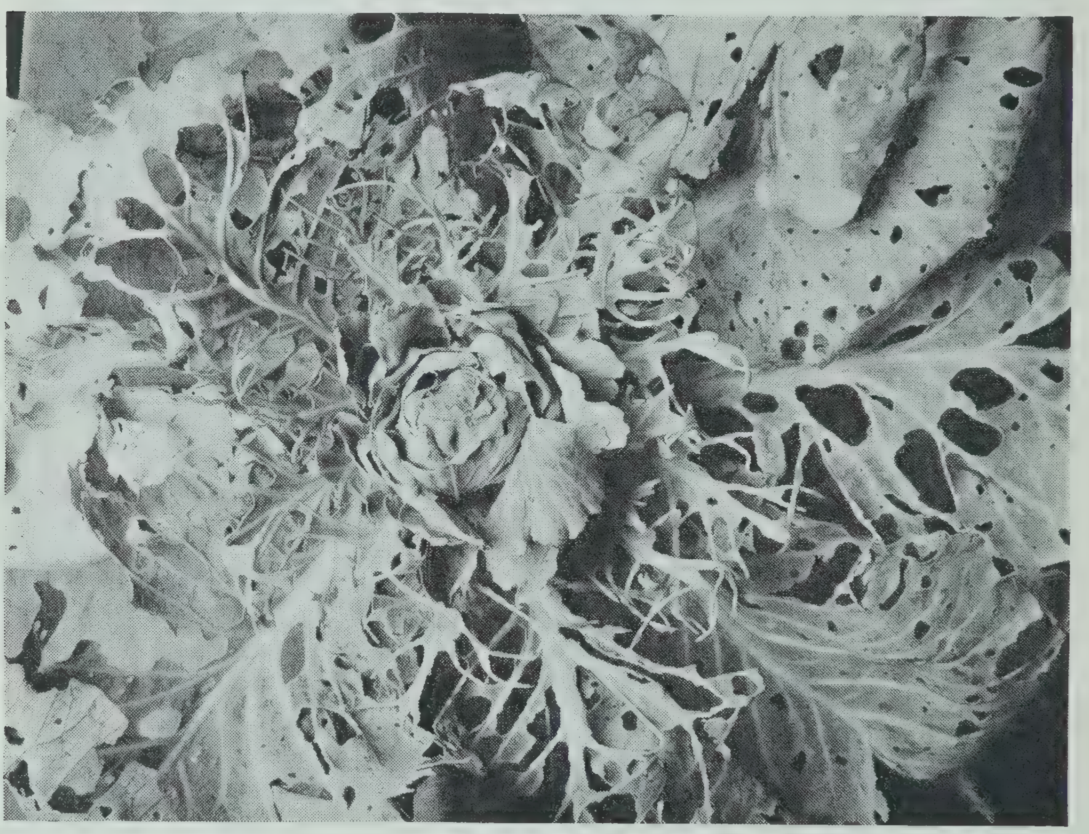


FIG. 147. A young cabbage plant, just starting to head, with most of the softer tissues of its leaves eaten away by the cabbage "worm" or caterpillar.

Physiological or constitutional disorders due to drought, high water table, soil alkali, starvation, extremes of temperature, or other environmental factors are often difficult to distinguish from those due to insects, fungi, bacteria, or virus diseases. Distribution or localization in the field where incidence of the symptoms is obviously associated with some peculiarity of soil, drainage, exposure, or other environmental factor is often of aid in classifying a disorder as to cause. In other instances it is not, as in a greenhouse where all of the plants in a bench have been overfertilized or where the soil has been made alkaline and toxic from the continued use of "hard" water. In such instances and in others where classification is difficult or impossible after rather close examination and study, resort must be made to the microscope, or the assistance of trained entomologists or pathologists must be sought. Reliance often may be placed in former observations and experience with the same or related crop or ornamental plants under more or less similar conditions.

INSECTS AND INJURIES DUE TO THEM

There are so many different kinds of insects that attack crop plants, and they cause injuries of so many kinds that anything approaching a comprehensive classification is too difficult and complicated for anyone but an entomologist. There is, however, a number of fairly distinct insect groups and characteristic types of injury that even the amateur may recognize and to which attention may be called.

CHEWING AND SUCKING INSECTS

In the first place, both entomologists and plant-growers classify insects into two great groups — (*a*) those with biting or chewing and (*b*) those with sucking mouth parts. The first group eats away and ingests portions of leaf, flower, fruit, stem, root, or other structure; it leaves the respective tissues more or less riddled with holes or tunnels, or skeletonized or consumes them completely (see Figures 147 and 148). The second group inserts bills into the soft interior tissues and sucks their juices, leaving intact the epidermal or cortical tissues, but perhaps the leaves are curled, twisted, dwarfed, or otherwise malformed (Figure 153). Some of the more common groups — groups and group names, however, that are recognized by the plant-grower rather than taxonomic groups recognized by the entomologist — will be briefly discussed here.

CATERPILLARS

First and foremost among the insect groups, both from the standpoint of number of kinds and of amount of damage inflicted on crops are *caterpillars* of one kind or another. They eat holes in plant tissues of all kinds or eat out the softer portions (see Figure 147), leaving those that are tough and woody, or they consume everything as they go even to the hardest wood. Usually they are called *caterpillars* when they work on the surface where they can be more or less readily seen, though sometimes they are called *slugs* (for example, the rose slug shown in Figure 148 and the pear slug), especially if they are covered with a more or less slimy coating. Caterpillars that live in the soil and eat the roots of plants are often called *grubs* (for example, the so-called *white grubs* common in sod land), though that term is likewise applied to some of the other kinds or groups of caterpillars to be mentioned later. Not infrequently, though erroneously, caterpillars are called *worms*, the term *worms* being properly applied only to a great group of less highly organized forms of animal life that are legless and of which the common earthworm or fishworm is one of the best examples. Among the caterpillars that are almost always referred to as worms are those that work on the foliage of cabbage (see Figure 147) and tomatoes. *Cutworm* is the name almost universally applied to a group of caterpillars that cut off the plant at or just below the surface of the soil and that eat principally at night and then hide away, usually beneath the ground, during the day. They are especially troublesome with some of the garden crops. Some kinds of cutworms, the climbing cutworms, climb to the tops of plants and feed on their uppermost branches at night. Caterpillars that spin a large web to

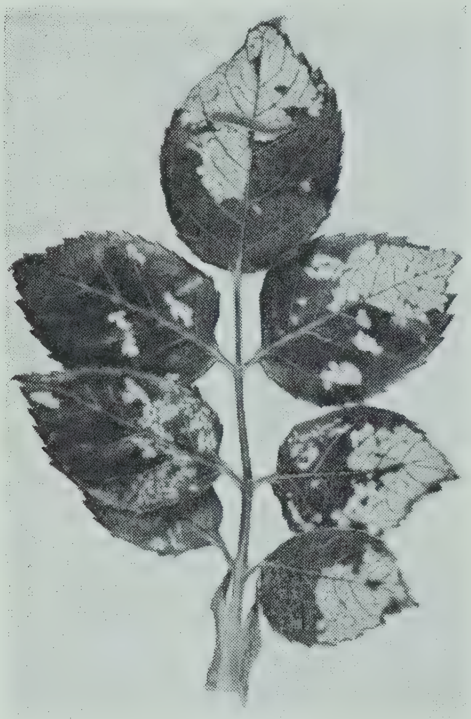


Fig. 148. A rose leaf partly skeletonized by the rose "slug," one of which is shown at work on the terminal leaflet.

which they periodically return for protection are called *tent caterpillars*.

The caterpillar is the immature or larval form or stage of an insect that when mature is a butterfly, moth, beetle, or perhaps the member of some other group or class to which it bears faint resemblance. As they hatch from egg, caterpillars are very small, sometimes hardly large enough to be seen except with the aid of a lens, but many of the common kinds finally attain considerable size, and as they usually grow rapidly and are voracious feeders, they often cause great damage within a short period.

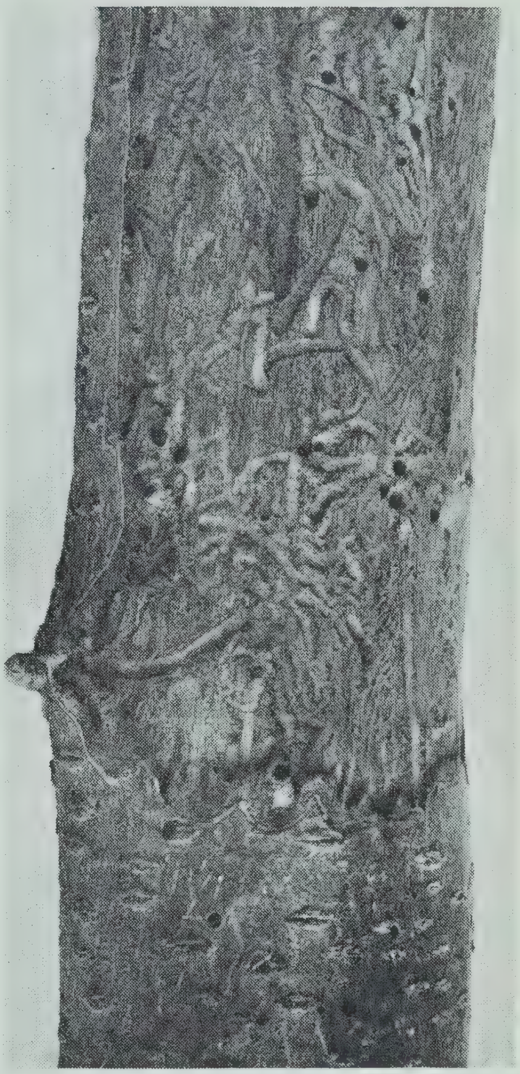


FIG. 149. Breeding galleries, just under the bark, of shot-hole or pin-hole borers.

BORERS AND GIRDLERS

Caterpillars that tunnel within roots or stems, either in the pith, as in the case of such kinds as work in the stems of the cucurbits, corn, and the cane fruits, or just under the bark (Figure 149), as in the case of many trees (apple, peach, maple, etc.), are usually spoken of as *borers*. Most of them are the larvae of moths or beetles. Often they may cause extensive damage before their presence is detected, for, unlike typical caterpillars, they are out of sight. Only when they tunnel to the surface so that the larvae themselves or their adult forms may escape or when their "frass" is extruded from such openings or when the stem or limb or whole tree suddenly wilts or ceases to grow or its foliage takes on an unnatural color, is there likely to be any suspicion of their presence. Those kinds that feed only in the outer layers of the bark or only in the pith may cause little damage. If, however, the pith borers burrow outward and eat much of the conductive tissues of slender stems such as those of the squash or cucumber, they cut off the supply of water and nutrients to the sections beyond and cause wilting and death. Borers that work principally in the cambium region between bark and wood girdle the branch or stem in question. Partial girdling is followed by the slowing down of growth on that side of the stem or limb, while its foliage acquires a yellowish cast; complete girdling causes death within a year or two depending on kind, age, and condition of the plant. Sometimes the bark and woody tissues of stems and branches are so riddled with borers of certain kinds that they appear to be literally "peppered" with their exit holes or openings. This particular group of borers is often referred to as *shot-hole* or *pin-hole borers* (Figure 149). Some kinds of borers are more likely to attack weak or diseased than strong, vigorous, healthy plants.

As just explained, some species working beneath the outer bark effect a partial or complete girdling of stem or branch, as the case may be. Another group of caterpillars may eat away outer as well as inner bark in the form of narrow bands encircling stems or branches. These are commonly called *girdlers* or *twig girdlers*. They are of more common occurrence in forest and ornamental plantings than in the orchard or with herbaceous crops.

MINERS

Another group of caterpillars, usually of small size even when full grown, eats out the soft tissues between the upper and lower epidermis of leaves, or burrows out shallow tunnels just underneath and next to the epidermis of stems and fruits. These caterpillars are known as *miners*. Often they can be identified by the characteristic patterns of their mines or tunnels. They are more frequently of small rather than major economic importance, for it is seldom that they destroy any considerable portion of the leaves, and the parts of stems or branches that they infest are for the most part physiologically inactive.

BEETLES

It has been stated that many caterpillars and borers are the larvae of beetles. Mature beetles, like their larvae, have biting or chewing mouth parts, and the adults of many species cause more or less damage to certain crop plants as a result of their feeding.

Among some of the more common in this group are the rose beetle or rose chafer, the Japanese beetle, the striped cucumber beetle, and the Colorado potato beetle. Some of these, as the last one mentioned, are often erroneously called *bugs*. Their larvae, which usually cause more damage than the adults, are called *caterpillars*, *slugs*, or *worms* or some other semidescriptive name.

MOTHS

This is a group of insects that as adults are night-flying, four-winged, and have sucking mouth parts. It includes species ranging from the familiar diminutive clothes moths to the large showy lunar and tobacco forms with a wingspread of four to six inches. The limited amount of feeding done by the adults seldom occasions much crop loss, but their larval forms include some of the most destructive kinds known. These larvae are typical caterpillars with chewing mouth parts that eat the tissues of leaf, bud, flower, stem, root, and fruit. Some belong in the borer group and are more commonly called *borers;* others are commonly classified as *caterpillars;* still others, even as larvae, are commonly referred to as *moths*. This, for instance, is true of such species as the gypsy moth, the brown-tail moth, the codling moth, and the oriental fruit moth.

WEEVILS

The term *weevil* is applied to both the adult and larval forms of a large group of rather small-sized, short, fat-bodied clumsy

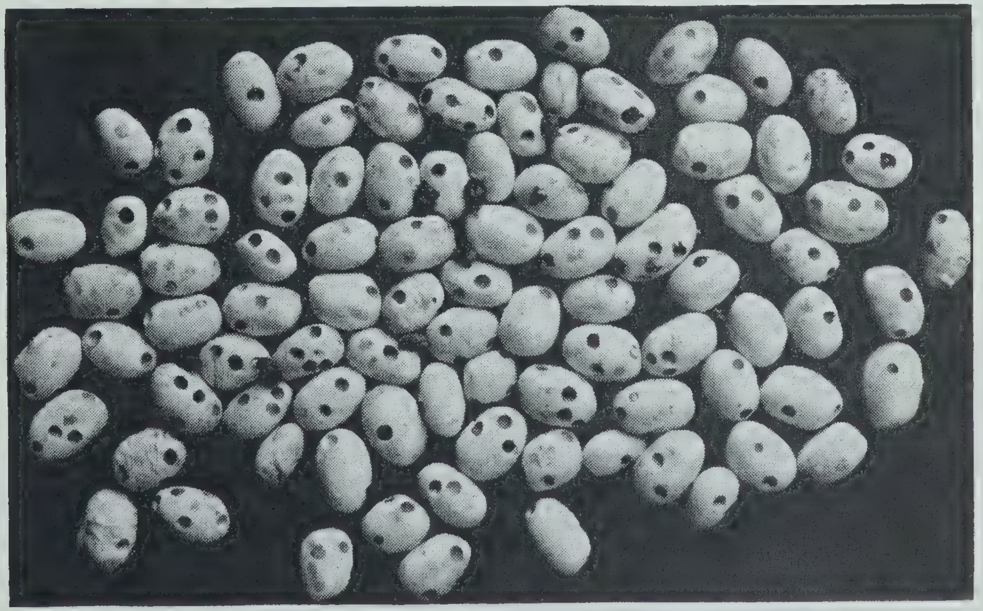


FIG. 150. Weevil-infested beans.

insects. They infest plant organs and tissues of many kinds but are especially troublesome in seeds of many species. The work of the bean weevil, typical of the group, is illustrated in Figure 150. Their eggs are generally laid on or in the partially grown seed pods; upon hatching the young larvae burrow into the seeds and spend their larval and usually their pupal stages there, living on the tissues of embryo and endosperm. Often the infested "seed," when mature, consists of little more than a seed coat surrounding the weevil. Though seldom referred to as *caterpillars*, weevils are often called *grubs*.

GRASSHOPPERS

Among the chewing insects that cause serious damage to crop plants of many kinds and that have an almost world-wide distribution are the grasshoppers. There are many species. Their eggs are laid in clusters or masses just beneath the surface of the soil, sod land being preferred. The adult "hoppers," upon emerging from the soil, are voracious feeders and consume practically every nonwoody part of most plant species. They sometimes emerge in hordes and lay waste over considerable areas to every living plant in sight. Grasshopper plagues have been recorded in many countries since the dawn of history. In more modern times with less extensive areas of unbroken sod land and with better methods of control, grasshopper injury has been somewhat less devastating, though it is still very great. Grasshoppers are often called *locusts*, and the locust plagues of history have been due to them, though that name has likewise been applied to an entirely different group of insects.

FLIES AND MAGGOTS

The name *flies* is given to a large group of two-winged insects of great economic importance. It includes many species whose larvae attack crop plants of many kinds, though for the most part little is seen of the adults, and they cause comparatively little injury. As a group the larvae of flies are commonly called *maggots;* though footless they find it possible to tunnel through soft tissues of stems, roots, and fruits much as do caterpillars, borers, or miners. Fungous infection and decay seem to follow the attack of maggots more universally and promptly than is true in the case of caterpillars. Some of the more common and troublesome species affecting horticultural crops include the cabbage, onion (Figure 151), turnip, and mushroom maggots and the so-called *fruit flies.*

The so-called *white flies* so common in greenhouses and on citrus trees are not true flies but are more closely related to some of the plant lice and leaf hoppers that will be briefly discussed later.

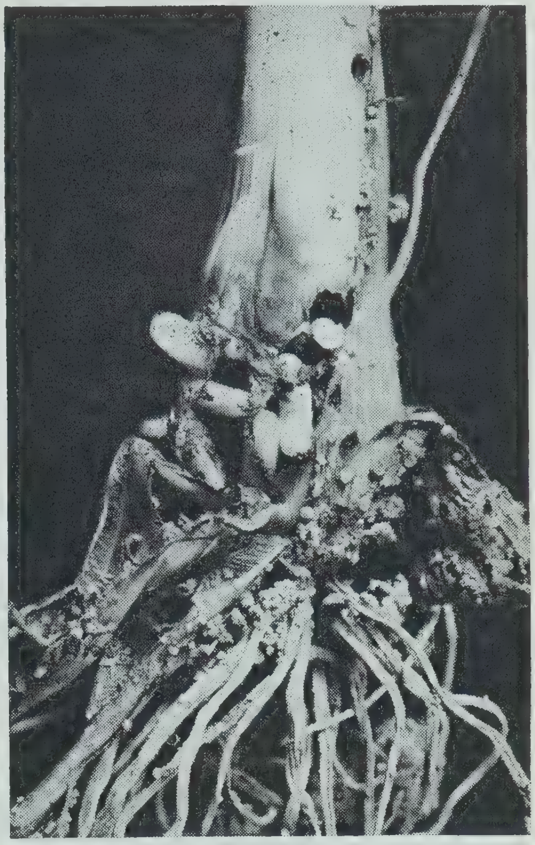


Fig. 151. Onion maggots and their work in a small onion. Enlarged about two diameters.

BUGS

In common parlance the term *bug* may be applied to almost any insect. Thus, the Colorado potato beetle is often called the *potato bug.* The entomologist, however, restricts the term to the members of a single, though important, order characterized by four wings (though some forms are wingless) and sucking mouth parts. This more restricted group includes a number of species injurious to crop plants — for example, the chinch bug, squash bug, and tarnished plant bug — most of which are comparatively resistant to the action of insecticides. Wilting, dwarfing, and other symptoms resembling those attending drought are more or less characteristic symptoms attending the attack of true bugs.

APHIDS OR PLANT LICE

Few insect groups cause more damage to a greater variety of plants than the aphids or plant lice. They are comparatively small but reproduce very rapidly and make up in numbers what they lack in size. Under favorable conditions a group or cluster of a half dozen or so on a shoot or leaf may increase to several hundred within a month's time. Some are winged and can migrate to other plants; others are without wings. Most species prefer to work on tender, succulent growth; consequently, they are found in greatest abundance near the ends of new shoots (see Figure 152) where they cause the leaves to curl around and over them, thus affording them protection from exposure to the elements and also from being reached by spray materials. Such shoots are stunted in growth and become misshaped. Fruits, flowers, and roots that are attacked by aphids are similarly stunted and deformed (see Figure 153), the result apparently not only of the extraction of some of their sap but also of the injection of certain poisons or toxins. There are both root and aerial forms, in some instances of the same species. Most aphids are comparatively soft bodied

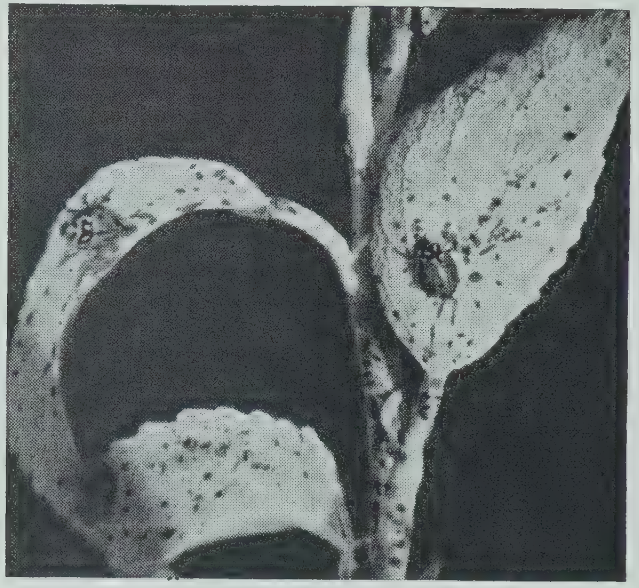


FIG. 152. Aphids or plant lice on the leaves and stem of a young apple shoot. Note the two ladybird beetles which are feeding upon the aphids.

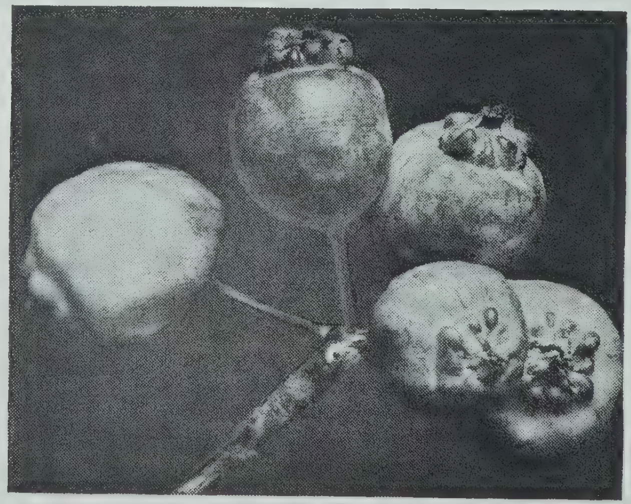


FIG. 153. The stunted, deformed apples of a cluster attacked at blossoming time by rosy apple aphids.

and readily killed by suitable spray applications, but some (the so-called *woolly aphids*) are protected by a woolly or cottony coating and are consequently more difficult to destroy.

THRIPS AND PSYLLIDS

Thrips and psyllids, though belonging to different insect orders, are both of almost microscopic size, having sucking or rasping mouth parts, and work principally on foliage and flowers. They often occur in such large numbers that the resultant drain upon the plant results in a distinct stunting. The flowers of thrip-infested plants may be undersized and fail to open normally or they may "blast." Thrips are especially troublesome with certain ornamental crops, such as the dahlia and gladiolus. Psyllids are less general in their attacks, but are the cause of much damage in pear orchards, where they stunt and dwarf both foliage and fruit and cause it to become covered with a "honey dew" which they secrete and which later is blackened and smudged with a sooty mold fungus.

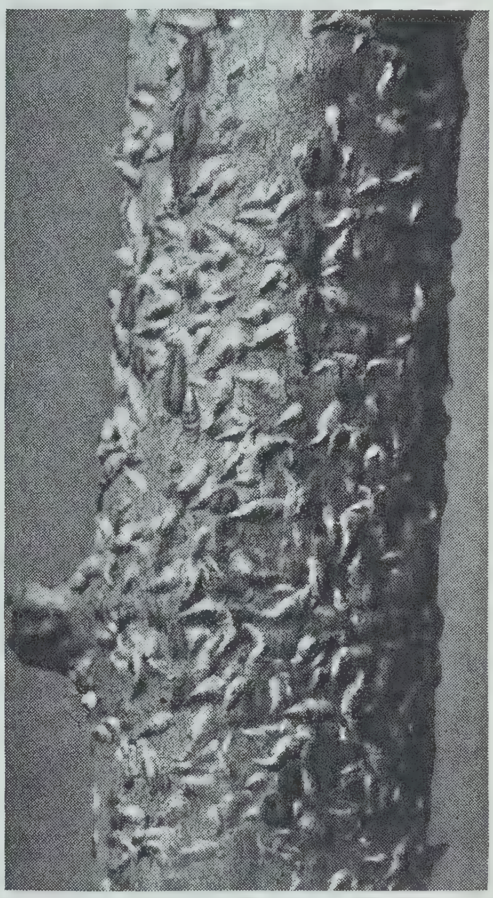


Fig. 154. Oyster-shell scales on an apple branch.

SCALES

As the group name indicates, each individual scale insect is covered by a protective scale or shield. Often the individuals become so numerous that together they literally encrust the stem, branch, leaf, or fruit (see Figure 154). When this stage is reached, the plant is usually greatly weakened by the steady drain upon it, and in extreme cases it may die. Some species of plants, such as the apple, are more resistant than others, such as the peach, to scale-insect attack. Similarly, some kinds of scale insects, as the San Jose, are more harmful than others, for example, the oyster-shell scale or bark louse. Scale insects are troublesome principally on woody species, though many herbaceous plants grown outdoors or in the greenhouse are subject to their attack. They are among the most resistant to insecticides of any of the insect groups, and control is sometimes difficult.

BEES AND WASPS

As a group bees and wasps are probably to be classified as beneficial rather than harmful insects. Bees in particular serve as pollinating agents for plants of many kinds. On the other hand, they are sometimes the cause of more or less damage to ripening fruits of certain kinds, particularly those that are sweet and juicy. They evidently like to feed on material of this sort. There is some question, however, as to whether they will break the skin of uninjured fruits or simply feed on the juices of fruits that have been pecked by birds or whose skin has been broken by other mechanical means.

GALL INSECTS

Abnormal swellings are found on the stems and leaves of many plants owing to the fact that the eggs of some insect have been laid in the stems or leaves at the points in question; the eggs have then hatched; and the larvae have tunneled into the stem or leaf tissues. Apparently the swellings or *galls* have developed more because of certain toxins or poisons secreted or produced by the developing larvae than because of any mechanical effect produced by them. So characteristic are the responses of certain plants to the stimulus of certain gall-inhabiting insects that the latter may be readily identified by the size, shape, and general appearance of the galls to which their presence gives rise. In general, galls are more numerous on ornamental than on fruit-producing plants and more numerous on native or uncultivated plants than on those that have been brought into cultivation.

EGG-LAYING AND FEEDING PUNCTURES

Blemishes of one kind or another due to the egg-laying or feeding punctures of certain insects are of rather common occurrence and often may be more serious than injuries due to either larvae or adult feeding. For instance, the characteristic egg-laying punctures of the plum and apple curculios result in a permanent disfiguration of the fruits, as shown in Figure 155. Should the eggs hatch and the larvae survive, the result will be a "wormy" and worthless fruit; even though the egg never hatches, the fruit is disfigured. The egg-laying punctures of the seventeen-year locust, or cicada, in the small shoots and twigs of young apple and other fruit trees are so deep that they weaken the twigs with the result that many break off, and the tree may be badly deformed and stunted. The egg-laying punctures of the snowy-tree cricket and many other species are almost as injurious as those of the cicada.

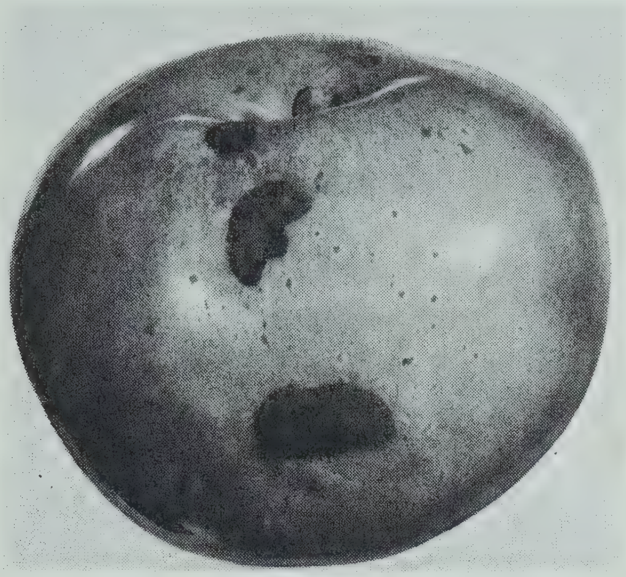


Fig. 155. Blemishes or "stings" on the apple caused by the egg-laying punctures of the curculio.

SPIDERS AND MITES

To the average person a spider is an insect, though the entomologist does not so classify it, because it has eight instead of six legs. For practical purposes, however, spiders and mites may be considered along with insects. Most kinds of spiders cause no harm to plants, but the so-called *red spider* is a serious pest. So minute are these spiders that they are barely visible to the naked eye, but they multiply very rapidly and literally thousands may infest a single leaf. The result is that so much of its juices is extracted by them that the leaf takes on a grayish cast, turns yellow or brown, and falls off. The spiders congregate especially on the under sides of the leaves where their delicate webs may be seen upon close examination. Their feeding habits are much like those of the aphids, but they do not cause the characteristic dwarfing and culling associated with aphid attack. Red spiders are especially troublesome in greenhouses, on a number of outdoor ornamentals, and on such small fruits as the raspberry and blackberry.

Leaf hoppers, a group of insects much more closely related to the aphids in both structure and appearance than to red spiders, feed upon and injure the foliage of many plants in much the same way as do the spiders.

FUNGI AND BACTERIA AND INJURIES DUE TO THEM

Though the number of species of fungi and bacteria that attack crop plants is apparently smaller than the number of insects, it includes a great diversity of forms that are the causes of many kinds of disorders. As in the case of insects, these organisms and the disorders to which they give rise are grouped according to their more prominent symptoms, but, if anything, the grouping is even more arbitrary and the lines between the groups less distinct. In spite of all this, however, the nontechnical classification of fungous and bacterial diseases is very useful to the plant-grower. It helps him to recognize the symptoms, perhaps partly to identify the specific disease and, more important, to employ a control measure that is likely to be effective. Some of the more important of these groups will be briefly discussed.

MILDEW

The term *mildew* is sufficiently descriptive of one type of fungous injury to make possible its almost certain classification. It is characterized by a surface growth, in some cases downy and in others powdery in nature, depending on the species of fungus involved. Though most commonly found on leaves, it is likewise often found on the surfaces of stems, fruits, and even flowers. It is more frequently found on new growth and young tissues than on those that have attained a greater degree of maturity. Accompanying, or perhaps more accurately as a result of, the surface mildew there may be more or less dwarfing and deforming of the structures that are affected. A characteristic deformity caused by mildew on flower stems is shown in Figure 156. Among the crop plants and ornamentals that, at least in some areas, are very subject to mildew attack are the rose, lilac, apple, and grape. Being surface growths, mildews are both easily seen and controlled, though numerous parasitic threads penetrate the living tissues of the plant and obtain their nutriment from them.

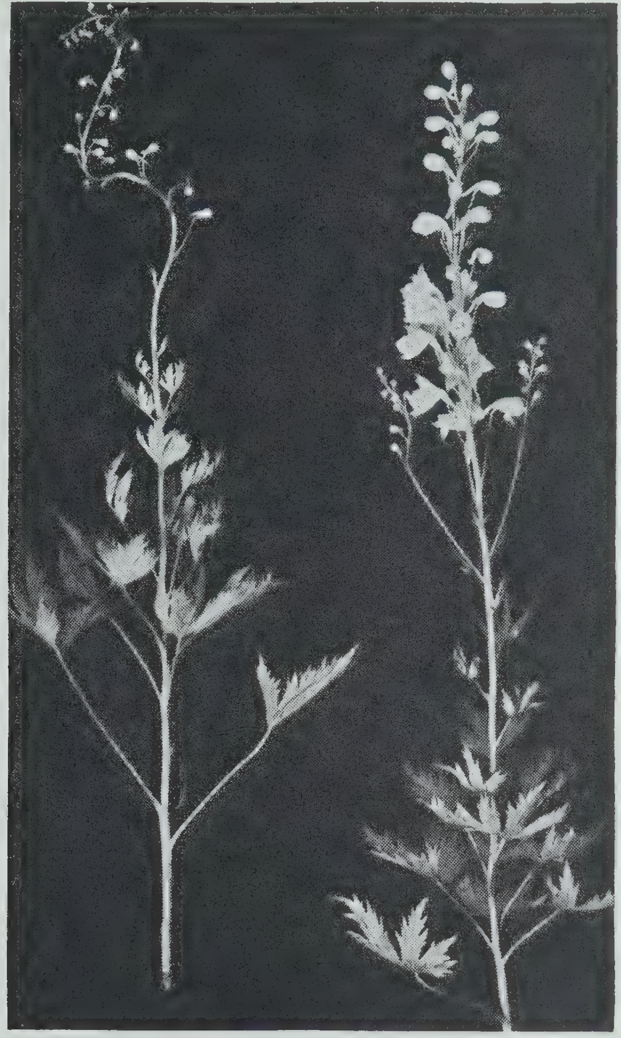


Fig. 156. Flower spikes of *Delphinium* — the one on the left is deformed because of infection with mildew; the one on the right is healthy.

RUST

Rusts, as the name implies, give to the infected plant a rusty appearance at certain stages. The lesions caused by rusts do not evenly cover large areas or surfaces, as is true of mildew, but rather take the form of spots or streaks (see Figure 157). Often these spots and streaks may be so numerous as to give the general appearance of complete coverage when seen from a short distance. Rusts also differ from mildews in that they are primarily subsurface rather than surface-growing organisms. As they reach maturity, however, they break through the epidermal tissues, making possible the release and spread of their rust-colored spores. Many of their common names — *wheat rust*, *apple rust*, *cedar rust*, *blackberry rust*, *white-pine blister rust*, *nail-head rust*, *orange rust*, etc. — indicate the host species or some more or less distinctive characteristic of the particular kind in question.

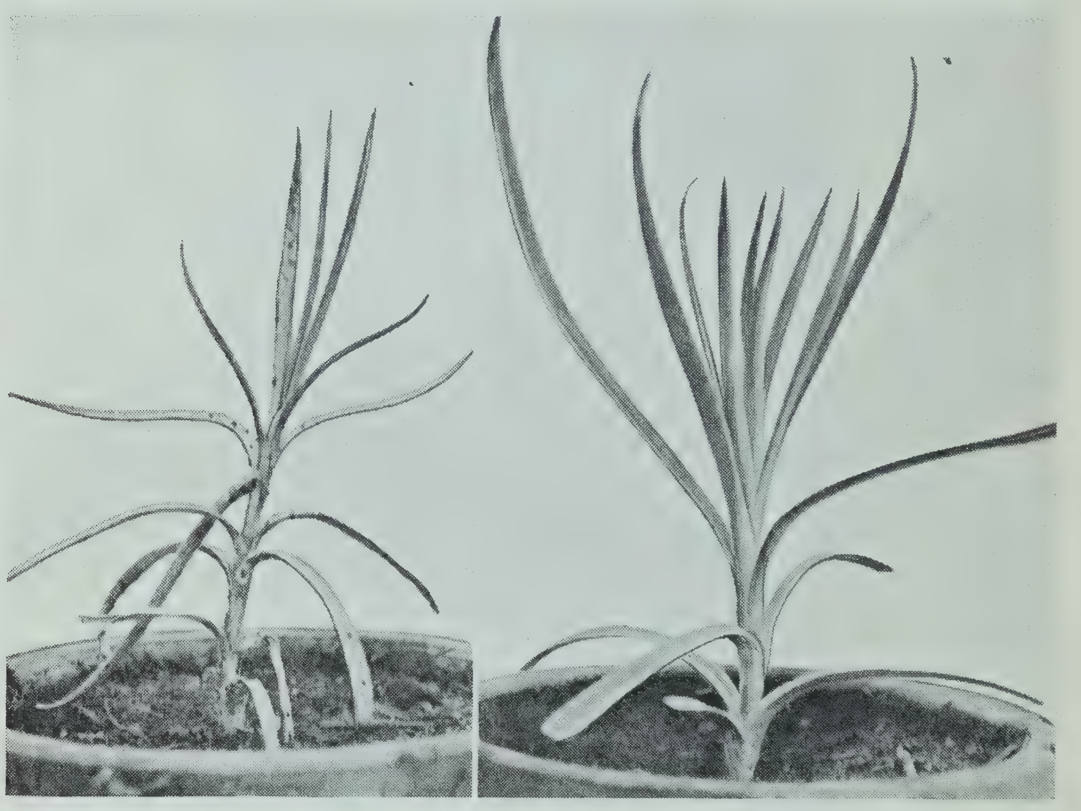


Fig. 157. Two carnation plants of the same age and variety. Note the rust lesions on the leaves of the plant on the left and the dwarfing effect that they have had on the entire plant. The plant on the right is uninfected.

A peculiarity of certain rust species is that in order to complete their life history they must live on different and often entirely unrelated host plants. Thus, the pine blister rust spends a part of its life cycle as a parasite in the needles of the white pine and the rest as a parasite in the leaves of the gooseberry or black currant. The cedar rust, pictured in Figure 158, has the apple as an alternate host. It cannot live indefinitely from year to year on either host plant, but must alternate from one to the other. This alternate-host habit suggests eradication of one of the host species from a given area as a means of control. In general, rusts are much more difficult to control than are mildews.

SPOTS — OF LEAVES, STEMS, FLOWERS, AND FRUITS

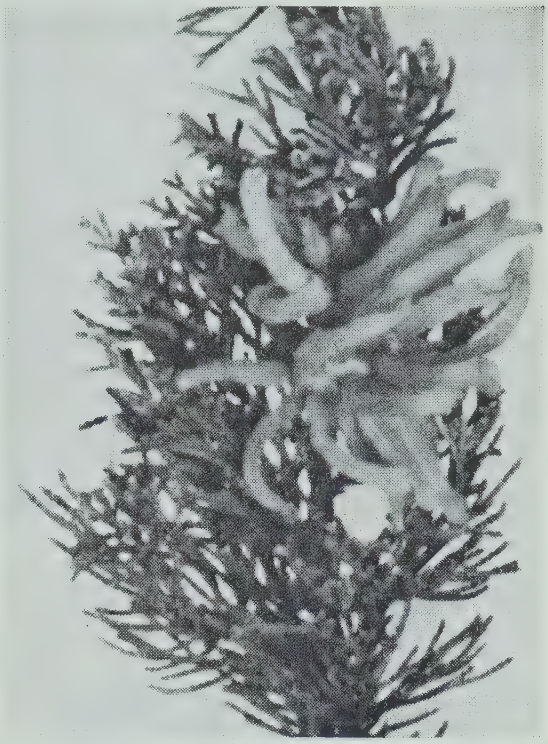


Fig. 158. A twig of red cedar (*Juniperus virginiana*) infected with the cedar rust that spreads from the cedar to the apple.

Rusts have just been described as causing distinct, more or less localized lesions from which the rust-colored spores are discharged at maturity. Spots of many sizes, shapes, and colors are found on the leaves, stems, and fruits of many species. Indeed, this rather loosely defined group is probably the largest of any here considered. Such names as *cherry-leaf spot*, *triangular leaf spot*, *frog-eye*, *black spot*, and *fly speck* are indicative of more or less distinctive characteristics of some of them. However, several disorders that are essentially *spot* diseases are commonly designated by some other name, such as *scab* (Figure 159) or *anthracnose*. Nomenclature and classification are still further confused by using terms that very obviously are not applicable to them. For instance, the strawberry leaf-spot disease is called strawberry *rust* as often as it is called *leaf spot*, though in no way does it answer the description of a rust.

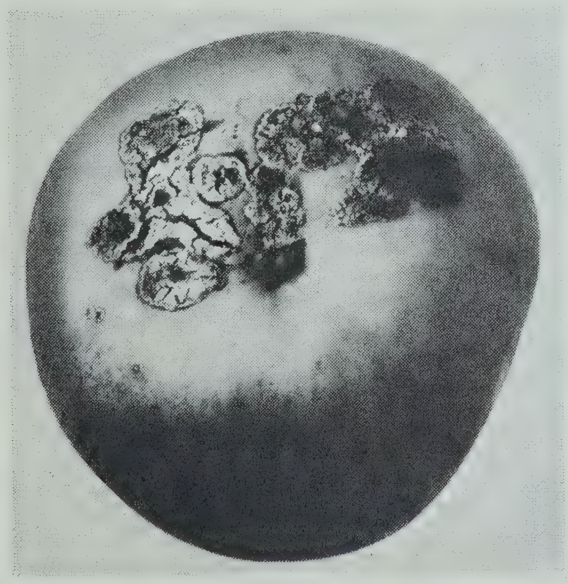


Fig. 159. Scab lesions on apple.

In general, the disorders classified here as *spot* diseases are strictly localized rather than systemic. That is, each spot is occasioned by a separate infection, instead of a single infection resulting in a spread throughout the plant or a considerable portion of it. It is often very difficult to keep plants entirely free from diseases of this character; on the other hand, limited infection is far less likely to cause serious trouble than perhaps a single infection of a disease that is capable of spread within the plant.

Spots more or less resembling those due to fungous or bacterial infection are often caused by other agencies, such as the stings of certain insects, overdoses or too high concentrations of certain spray materials, localized killing of tissues due to drought, hail bruises, etc. There is always occasion for close examination to eliminate such factors as causal agents before definitely attributing the injuries to fungous or bacterial infection.

CANKERS

Cankers, like spots and rusts, are strictly local infections. The line between them and some kinds of spots, especially those that are designated as anthracnoses, is difficult to draw and arbitrary at best. In general, however, cankers are found on stems, branches, and roots rather than on leaves and fruits; they cover larger areas than do spots; they are likely to be less regular in outline but have definite margins; they are generally deeper seated, in many cases extending down to, or perhaps into, the woody

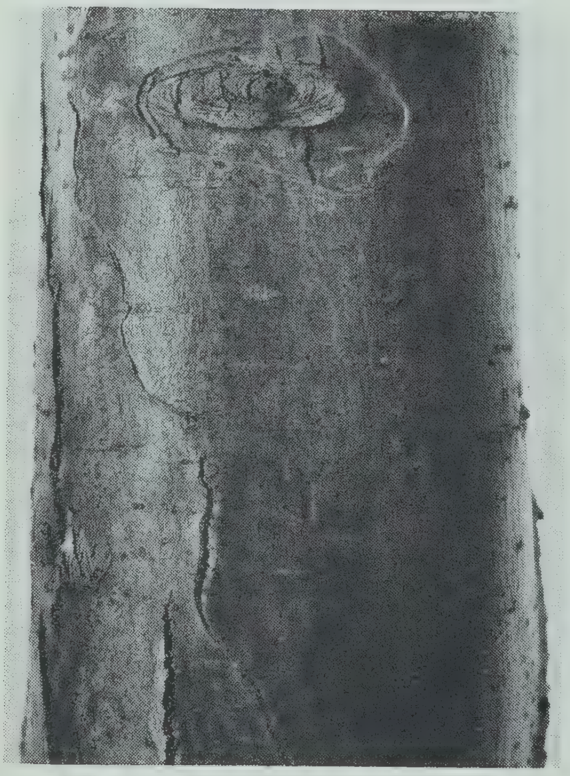


Fig. 160. A section of an apple branch showing a fire-blight canker along its left side. Its boundaries are indicated by the cracks at the edges of the sunken area. The slightly sunken area characterized by a rough bark near the top of the photograph is a normal condition associated with aging of the branch. Underneath the rough surface bark of this small area the inner bark layers are alive and nealthy. The dead cankered tissue at the left extends to the wood.

tissues. In many instances, cankers penetrate deeply into the wood or encircle stem, branch, or limb, girdling and killing everything above that point. They are consequently regarded as more potentially dangerous infections than spots. Many crown, trunk, or stem cankers are caused by fungi or bacteria (Figure 160) that are responsible for lesions of an entirely different character on leaves, flowers, or fruits of the same species. Thus, the black-rot disease of apples, as the name implies, causes a soft decay of the fruit; it likewise causes a "frog-eye" spot on the leaves and a canker on the limb and smaller branches. The so-called *fire-blight* bacillus of pears causes a soft rot of the fruit; blights the blossoms, leaves, and young shoots; and invades crown, trunk, and limbs in which it causes cankers.

Often confused with cankers caused by fungi and bacteria are lesions of similar appearance due to mechanical injury, low temperature (Figure 161), or even the attack of certain kinds of insects. Lesions of this type are sometimes referred to by such terms as *frost canker.* It is sometimes necessary to examine cankered areas rather carefully in order to be certain as to what may have caused them. This is especially true if they have started to heal over.

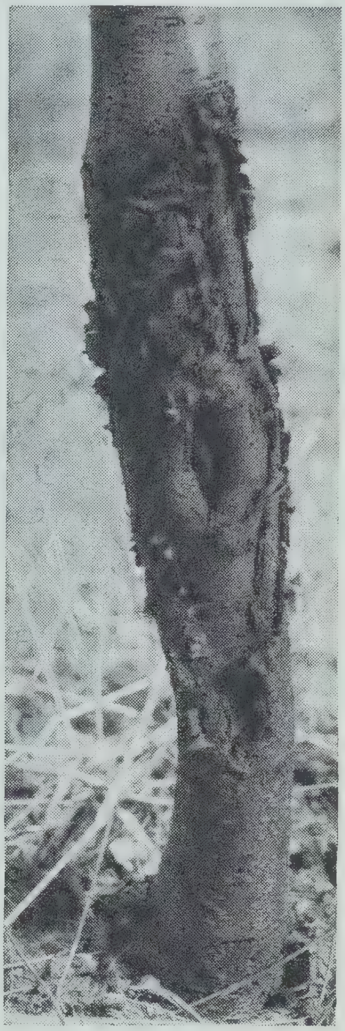


Fig. 161. A frost canker on the trunk of a peach tree that has nearly healed over.

KNOTS AND GALLS

Hardly to be distinguished from certain types of cankers are excrescences or malformations, especially of the woody tissues, that are often referred to as *knots* or *galls.* These occur on both stems and roots of many species. Warty growths of this type are formed at the point of union of stock and cion, especially in root-grafted stock. Sometimes they are due to parasitic attack; sometimes they represent simply a proliferation of normal, healthy callus tissue. In view of the fact that these excrescences occur just above, at, or just below the crown, they are often called *crown gall*. Above-ground excrescences are designated by such names as *black knot*, *burr knot*, and *burls*. Galls due to fungous attack may usually be distinguished from at least many of those due to insects by the fact that they are variable in size, irregular and unsymmetrical in outline, and have a rough surface.

ROTS

Many species of fungi and bacteria cause a decay of the tissues that they infect. Most rots are localized infections, though spread from the point of infection may be rapid and soon involve an entire fruit or fruit cluster or root, stem, bulb, or tuber. Such names as *brown rot*, *black rot*, *bitter rot*, *soft rot*, *dry rot*, *blue mold*, and *heart rot* are commonly applied to them and are more or less descriptive of their leading symptoms. The mycelium of some of the decay-causing organisms is able to penetrate the unbroken epidermal or cortical layers of the plants that they parasitize; that of others is unable to do so, and entrance is gained only through breaks caused by insect attack, mechanical injury, or the openings made by the growth of other fungi such as scabs or leaf spots. Bruises occasioned by careless harvesting, handling, and packing methods are probably indirectly responsible for more decay of fruits than are all others. Similarly, most heart rot in trees is traceable to pruning or other mechanical wounds that have not been afforded protective treatments and have thus exposed susceptible tissues to infection. In these cases, probably the most practicable control measures are those designed to reduce surface injuries to a minimum. *Damping-off* of seedlings and of cuttings is a type of rot or decay of soft succulent stem tissues caused by soil-inhabiting organisms that thrive in a moist soil and a humid atmosphere.

BLIGHT

The term *blight* is even less specific than is *spot*, *canker*, *rust*, or *mildew*, for many disorders that rather obviously could properly be classified in one of these latter groups are referred to as *blight*. Thus, the so-called *early blight* of potatoes is in reality a leaf spot, and in France the mildew of grapes has often been called *American blight*. Better usage restricts the term to diseases where infection is localized in the sense that perhaps the entire plant is not at first affected, but rather individual shoots or branches, though spread to, and perhaps destruction of, the entire plant may soon follow. However, a typical blight is not localized to the same degree as rusts, spots, and cankers in which there may be many lesions on a single fruit, leaf, or shoot. Cane blight of bramble fruits and fire blight of the pome fruits are examples of typical diseases of this class.

WILT

Wilting is a characteristic drought effect, but wilting from drought is usually a temporary condition, followed by a restoration of turgor at nightfall or upon the addition of water to the soil. Furthermore, wilting due to drought is a gradual process, the plant showing some sign of wilting one day, then recovering, then showing more severe wilting the next day and still more the next, until permanent wilting finally occurs. Wilting may also occur in poorly drained field soils following heavy rainfall or in greenhouses following overwatering.

Wilting due to fungous or bacterial attack shows up quickly, often suddenly, and there is seldom any temporary recovery. A cane or branch or an entire plant that is fully turgid one day may show extreme wilting the next, perhaps in spite of a moist soil and a humid atmosphere. It is generally due directly to a plugging of the water-conducting vessels by the growth of the invading organisms. Wilt diseases are more common and serious in herbaceous than in woody plants. Among the plants most commonly affected by wilt are tomatoes, the cucurbits, the dahlia, and the garden aster.

SEED-BORNE DISEASES

There are two general types or classes of seed-borne disease: (*a*) those, such as corn smut, in which the spores or mycelium of the organism are present within the tissues of the seed as it matures and are thus carried with it to wherever it may be planted, invading the newly formed parts of the plant as it grows, and (*b*) those in which the spores are lodged on the surface of the seed, ready to infect the young plant during or after germination. Diseases of the latter type can be controlled by treating the seed with a suitable germicide; those of the former type cannot be controlled in that way. Seed-borne diseases and seed treatments seem to be relatively more important with agronomic than with horticultural crops.

More or less comparable to seed-borne diseases are those that are carried by bulbs, corms, tubers, and other specialized buds and stem structures. Treatment for such diseases before planting has become a standard practice with many growers.

SOIL-BORNE AND ROOT-INFESTING ORGANISMS

Most of the spores of parasitic fungi find their way to the soil, though, of course, some are carried directly to the surfaces of plant tissues which they can penetrate and infect upon germination. Many cannot long survive in the soil and are thus eliminated as sources of future infection. In the case of many species, however, the organisms reach the soil in an immature stage in the plant remains — infected dead leaves, bark, twigs, etc. There they complete their life cycle and produce spores to infect new tissues some weeks or perhaps months later. The apple-scab and the brown-rot (of stone fruits) fungi are of this class. In such instances, the soil simply affords a suitable place for the organisms in question to remain between periods of active growth in the tissues of living plants. Were they to remain there much longer, they might be destroyed by normal weathering processes. In still other species, the entire life cycle of the parasitic organisms is completed below ground within the soil or within the plant roots. The spores or other vegetative structures of many such organisms are capable of surviving for years in the soil, even though no plants are grown on it of the kinds whose roots they are able to parasitize. These are soil-borne organisms in the strictest sense, and the group includes a number of the most troublesome plant diseases. Some of them, as the crown gall of cane fruits, do little more than dwarf or stunt the entire plant; some, as the tomato wilt, stunt the plant and cause wilting; others, as the celery yellows, cause stunting and yellowing of the foliage; still others exhibit other symptoms — symptoms that often make their definite diagnosis difficult because they resemble so closely those of parasites belonging to other groups or classes. As a rule, the soil-borne diseases have what appears to be a systemic rather than a localized effect, the entire plant displaying the characteristic symptoms.

Soil-borne diseases are among the most difficult to combat effectively.

VIRUS DISEASES

The so-called *virus* diseases in many ways resemble some of those caused by certain fungi. They are generally systemic in character, rather than localized, though sometimes they may exhibit distinctly localized symptoms. Propagation or inoculation tests show, however, that usually the entire plant carries the infection. The infective agent, principle, or *virus* is supposed to be an organism of submicroscopic size, though there is the possibility that in some cases it is something more comparable to an enzyme. For the most part, virus diseases are rather highly infectious, infection being spread by such agencies as insects, birds, cultivation, and pruning tools. Some of the names, for example, *yellows*, used to designate them are identical with those applied to diseases of other plants caused by fungi, bacteria, or perhaps unfavorable environmental factors.

MOSAIC

The term *mosaic* is applied to many disorders of the virus type. It describes rather accurately one of their most characteristic symptoms, a mottled or marbled appearance of the leaves in which green and yellowish areas of irregular shape, variable size, and indistinct borders alternate and intermingle. The result is a kind of mosaic or patchwork of color. Sometimes the color pattern is fairly distinct; again, it is very indistinct, in which case the name *mild mosaic* may be applied. Distinctness of color pattern in the mosaic diseases of some species varies with season of year, sometimes becoming almost completely masked. Among the more common plants seriously affected with mosaic diseases are the potato, tomato, tobacco, peony (Figure 162), Easter lily, and the red and black raspberry. Mosaic-infected annuals may survive the season or die early; mosaic-infected perennials may live for many years, or they may die prematurely. In either case, their vegetative growth is usually more or less stunted, their flowers are deformed, and their fruits are lacking in quality and worthless.

Often confused with mosaic is a mottled condition of the foliage of certain species caused by certain nutrient deficiencies. This is especially common in the citrus fruits, though it is by no means limited to that group.

Not to be confused with mosaic is the normal variegated condition found in the leaves of many varieties of ornamentals (see

Figure 163) — for example, croton (*Codiaeum variegatum*), cyclamen (*Cyclamen persicum*), Rex begonia, and caladium (*Caladium bicolor*). On the other hand, there are some plants that are valued as ornamentals principally because of their variegated foliage (for example, *Abutilon striatum Thompsoni* and *Pittosporium tobira variegata*) in which the variegation is due to a mosaic disease which is promptly transmitted to the stock upon budding or grafting. This is often spoken of or classified as *infectious variegation.*

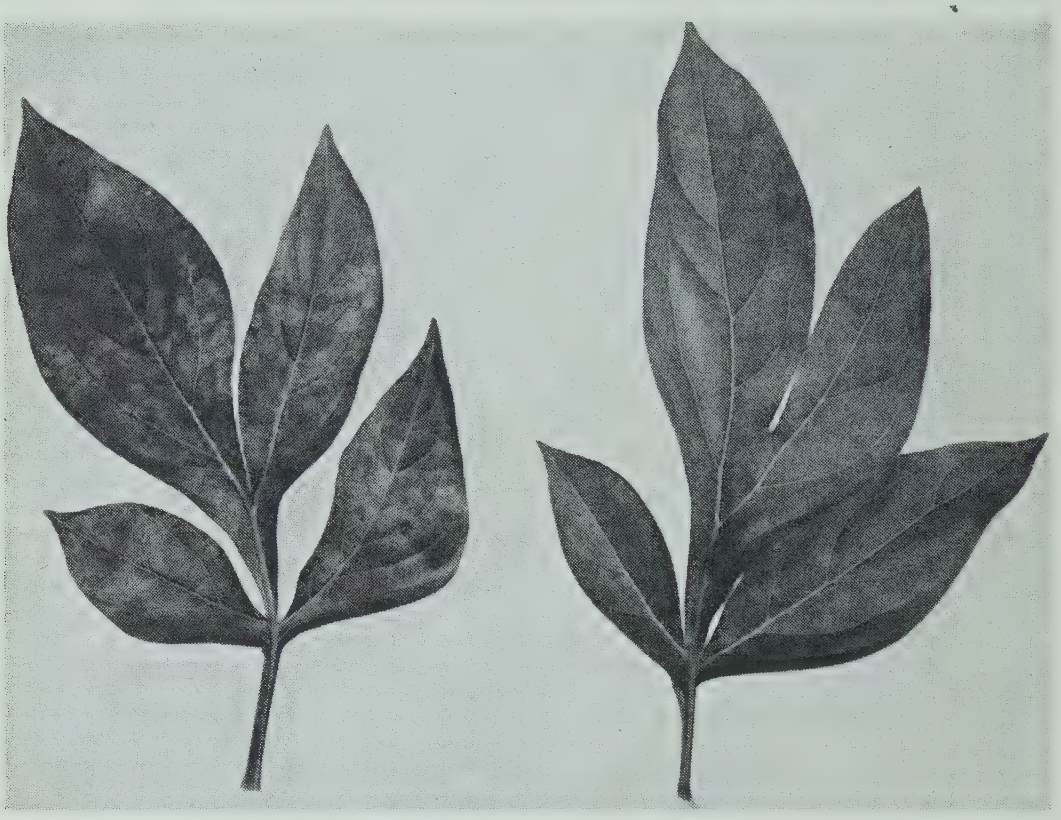


FIG. 162. On the right is a healthy peony leaf; on the left is one that shows mosaic symptoms.

YELLOWS

The virus diseases of some species or varieties of plants are characterized by foliage that is not mottled but that develops rather uniformly a yellow or yellowish-white color. These diseases are often designated as *yellows.* The yellowing may or may not be accompanied by decreased size and malformation. Peach yellows, potato yellow dwarf, and aster yellows are diseases of this type.

A nutritional disorder, sometimes associated with iron deficiency or with too alkaline a soil reaction or with some other nutrient deficiency or lack of nutritional balance, that in some of its symptoms resembles yellows due to virus is called *chlorosis* (see Figure 70). A chlorotic condition, if due to virus, is infectious; if due to faulty nutrition, it is not.

LITTLE LEAF, STUNTING, ROSETTE, ETC.

In Chapter VIII on "Plant Nutrients as Limiting Factors," the terms *little leaf*, *rosette*, *dwarfing*, and *stunting* were mentioned as names applied to certain deficiency diseases. Disorders of certain plants, similar in appearance, are likewise due to some of the virus diseases. In the first case, there is present no infectious principle by means of which the disorder can be spread to healthy plants, and it can be remedied by proper treatment; for the other, no remedy is known, and spread to other plants may be expected.

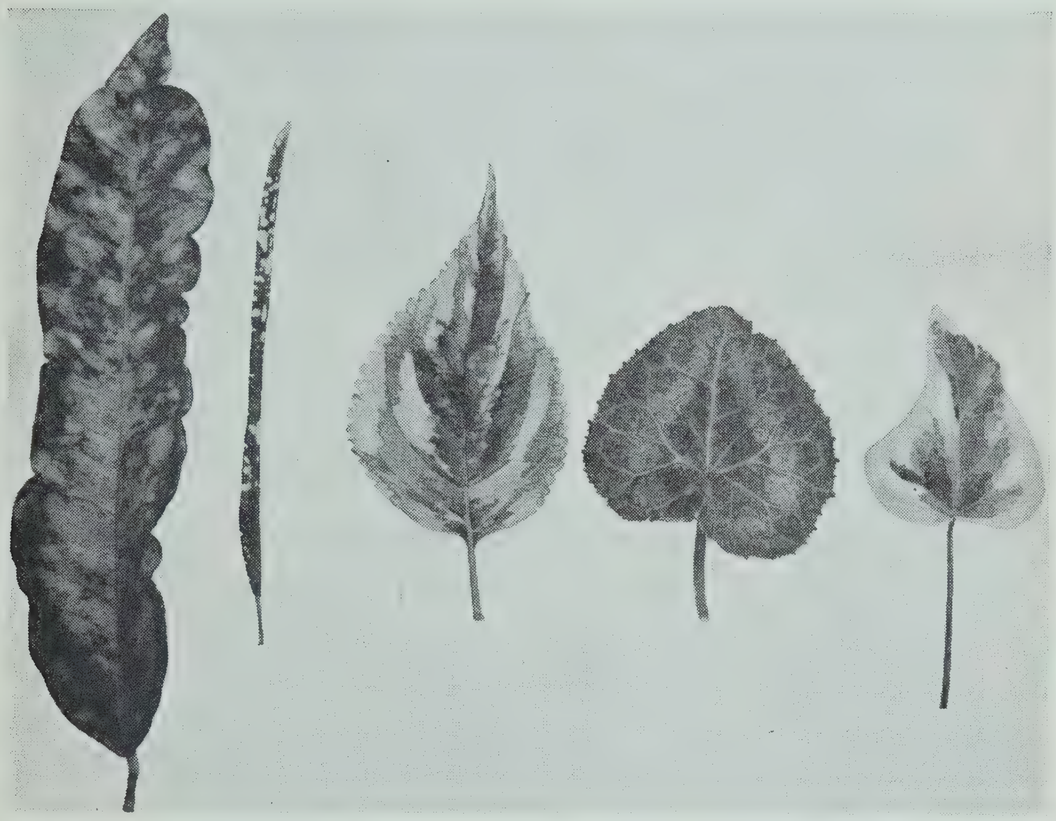


FIG. 163. Healthy leaves showing different types of variegation. The two on the left are different varieties of croton (*Codiaeum variegatum*). Their variegated patterns are due to irregular distribution of pigments. The center leaf is a *Coleus verschaffeltii;* the one on the right is an English ivy (*Hedera helix*). In both these species variegation is due to the association together of two genetically different kinds of tissue, an association known as a *chimera*. The color pattern in the second leaf from the right (*Cyclamen*) is due to alternating areas of loose and compact spongy parenchyma tissue.

CONSTITUTIONAL OR PHYSIOLOGICAL DISORDERS

In the chapters on water, nutrients, temperature, and light as limiting factors, attention was called to numerous deficiency symptoms and disorders due to too little or too much of some substance or to some extreme environmental condition or perhaps simply to a lack of balance between the several substances or environmental factors. Probably enough space has been devoted to them under such headings as "Starvation," "Drought Effects," "Winter Injury," etc., to make it unnecessary to go into any considerable detail regarding them here. However, some of these constitutional or physiological disorders present symptoms very similar to those of some of the virus and fungous diseases or even to those due to the attack of certain insects. This makes it desirable to point out methods by which some of the confusion in diagnosis and classification can be avoided.

Seldom are all the trees in an orchard or all the plants in a field or even a garden under strictly uniform conditions. There are differences in soil texture and composition, available moisture and drainage, in elevation, in exposure to sun and wind. Even within a greenhouse or over a single greenhouse bench or bed there may be substantial differences in temperature, humidity, air currents, and other features of environment owing to proximity to glass, location of heating pipes, etc. Associated with such differences are differences in fertility, mean and maximum temperatures, light intensity, rate of evaporation, and other factors and conditions to which plants react and respond in their growth. If a plant disorder that may be suspected as being due either to some fungus or to some environmental condition appears, observation as to its distribution in the orchard, field, or garden may point very clearly to one agent rather than to the other as its cause. Fungous or insect attack is not nearly so likely to be localized in the field — for example, on a northern exposure or in the most fertile area — as is a physiological disorder due, say, to low temperature or to high water table. We find sun scald on southern rather than northern slopes, symptoms of starvation on denuded hill tops or sharp slopes, such as are shown in Figure 80, rather than in the valleys where the finer, more fertile soil has been deposited by wind and water.

The way in which an infectious disease or an insect infestation spreads — that is, in rapidity and direction — from where it starts to new or surrounding areas is usually materially different from the spread of a physiological disorder. Of course, insects and fungi of different kinds thrive best in certain environments, just as do their host plants. For instance, the scab disease of the potato grows better in a neutral than in an acid soil, the peach-root aphid multiplies more rapidly and causes more damage in a soil of light texture than in one of heavy texture. Care is therefore necessary not to base diagnosis exclusively on spatial distribution, but, taken along with other things, it aids greatly in classifying disorders as to causes. As already pointed out, the symptoms of many kinds of injurious insects and fungous and bacterial diseases are localized within the plant, in the form of rust or dead or discolored lesions, malformations or disfigurations of various kinds. In the main the constitutional or physiological disorders affect the plant as a whole, in this respect more closely resembling diseases of the virus type.

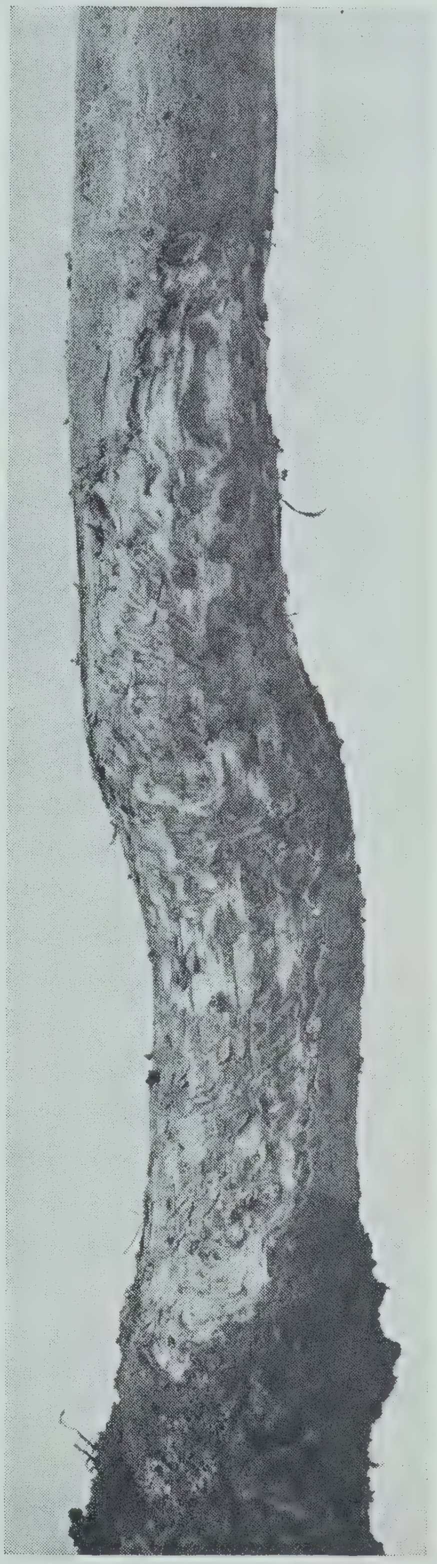


FIG. 164. The trunk of a small tree that has been girdled by rabbits.

MISCELLANEOUS PESTS

Besides the disorders due to insects, fungi, bacteria, viruses, and those associated with unfavorable conditions of environment, there is a considerable number caused by miscellaneous agencies. A few of these will be briefly discussed.

Rabbits and *field mice* have long been regarded as among the more serious pests of the orchard. Mice eat the bark from around the crowns of trees of certain kinds; rabbits feed somewhat higher on trunks and branches that may be within their reach (see Figure 164). In either case the trees or limbs are partly or completely girdled. Young apple trees are especially subject to injury from these rodents, though trees of any size and age may be attacked. When starvation faces them, they often eat the bark of pears, peaches, plums, and other fruits.

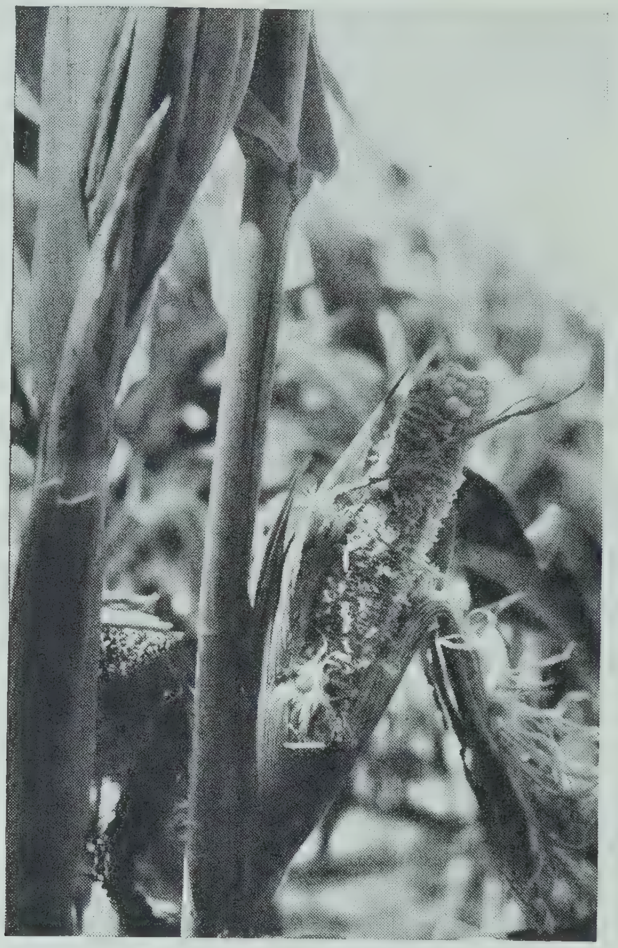


Fig. 165. Sweet corn damaged by crows.

Moles are often very troublesome in lawns and gardens. Though they probably do most of their burrowing in search of grubs, they eat both seeds and roots.

BIRDS

All the available evidence indicates that birds do far more good than harm. They consume great numbers of insects and weed seeds and are often a major factor in holding certain injurious species in check. Some of the predators, for example, the owls, are very effective in reducing the field-mouse population, and hawks destroy many rabbits. On the other hand, there can be no question as to the damage that they sometimes inflict on growing or ripening crops. Crows and pheasants pull up and destroy germinating seeds; they are especially partial to grain, either that recently planted or that which is maturing (see Figure 165). Partridges feed on the large nutritious flower buds of the apple and other fruits during periods when the ground is covered with snow and other food supplies are becoming exhausted, sometimes practically stripping whole trees, or even orchards. Starlings, robins, and many other kinds often cause inestimable damage to ripening cherries, strawberries, and other soft fruits (see Figure 166).

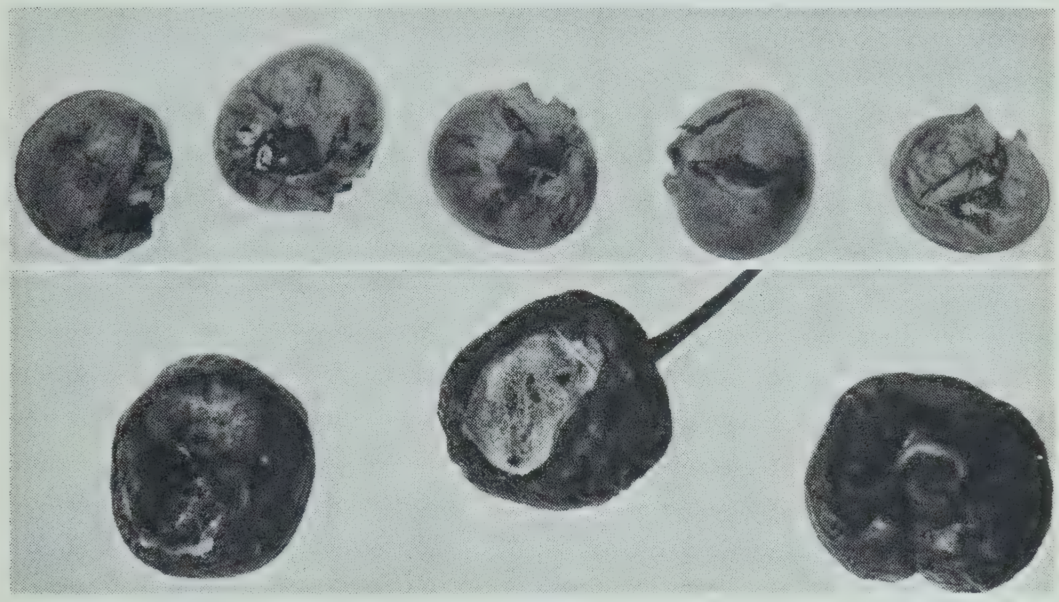


Fig. 166. Above is a row of cultivated blueberries showing injury by birds; below are three sweet cherries that were pecked by birds, the mechanical injury being followed by decay.

NEMATODES

In sections where the soil seldom or never freezes to a depth of at least several inches and in northern greenhouses one of the worst pests is the *nematode*, a true worm of almost microscopic size. They are found in great numbers in some soils and invade the small feeding roots and rootlets, causing irregular swellings and interfering with both water and nutrient absorption. The result is a dwarfing or stunting of the plant more or less proportional to the number of roots infested. The disorder is often designated as *root knot.* Fortunately, some species and varieties are immune or very resistant to their attack, a fact well brought out in Figure 167.

MECHANICAL INJURIES

In the discussion of rots, mention was made of the fact that many kinds of decay organisms are able to gain entrance to tissues which they are able to penetrate and destroy only through cracks or breaks of one kind or another in the epidermal or cortical layers. Mechanical injuries are the most important of the several factors responsible for such breaks in the natural protective armor of most plant organs. Many of these are due to lack of proper care in planting, cultivating, pruning, harvesting, or packing.

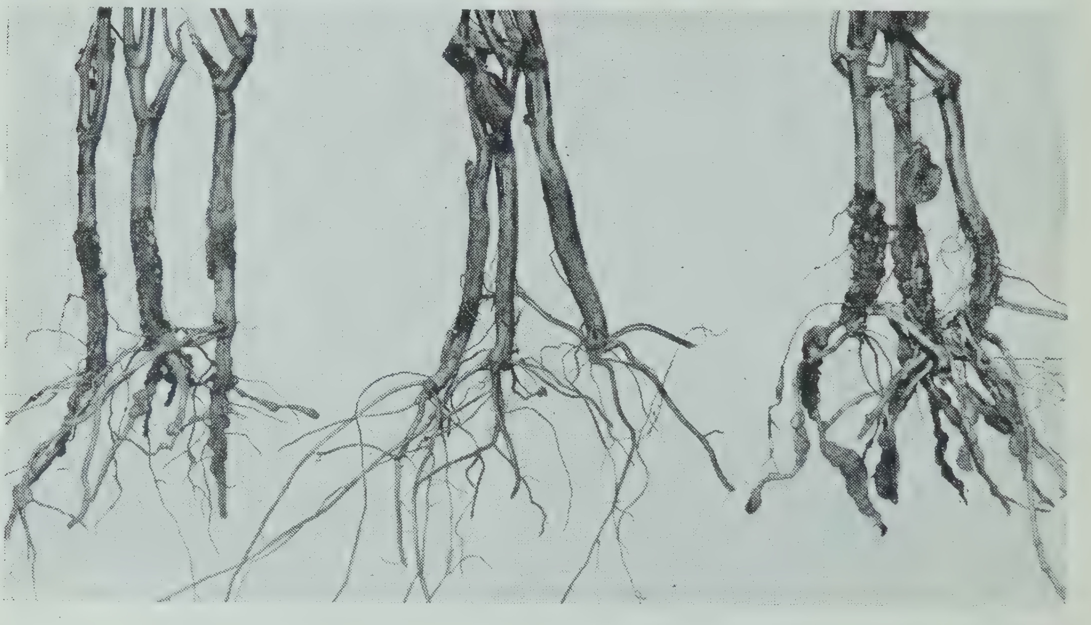


Fig. 167. Root knot, caused by nematodes, on the roots of garden beans. The photograph shows the difference in susceptibility of different varieties. On the left, Kentucky Wonder, and on the right, McCaslan, both susceptible varieties. In the center, Alabama No. 1, a resistant variety. All three lots were grown side by side in heavily infested soil.

Besides such injuries which are very largely avoidable, are those due to hail, limb rub, wind "whip," and similar causes, and not infrequently any one of these may be the cause of very extensive losses. Hail storms result in bruising and battering of fruits, limbs, and twigs and in shredding and tearing of leaves. The injuries to fruits and twigs may heal over through the formation of a layer of cork underneath the injured tissues, but there are likely to be more or less scarring (see Figure 168) and malformation. Continued rubbing of developing fruits against adjacent spurs, shoots, or larger limbs often results in a much thickened, dark-colored epidermal or cortical area, and this is sometimes accompanied by malformation. Wind of gale intensity causes lodging of herbaceous plants, breakage of limbs, whips flowers, leaves, and fruit, depending on the kind and stage of development of the vegetation when it comes. Shredding is usually much more severe in the case of large-leaved plants such as the banana and many of the palms. Hard beating rains are especially damaging to germinating seeds and young seedlings, packing the soil so tightly over or around them that many are destroyed. Lightning splits and ruins shade and forest trees; striking a grape wire trellis, it may kill all of the plants in the row. The weight of snow may bend shrubs and limbs to the ground and result in much breakage. The list might be extended almost indefinitely. The wonder is not that many plants are injured but that so many are as free from injury as they seem to be.

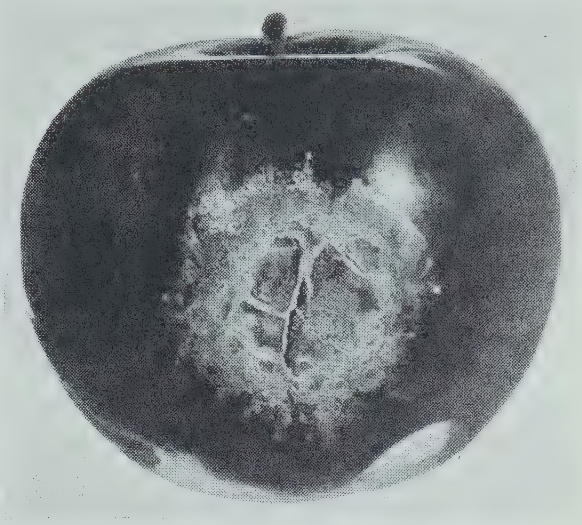


FIG. 168. Sun-scald injury on apples.

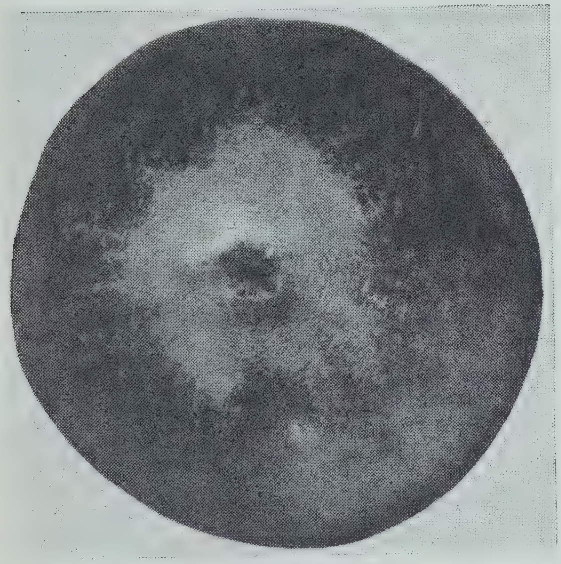


FIG. 169. A frost ring on an apple. These russeted rings or areas surrounding the calyx of apples and pears are caused by frost occurring shortly after the fruits have set.

When properly grown in a suitable soil, many short-lived plants, the annuals, biennials, and likewise many herbaceous perennials, reach maturity or the end of a season's growth with few evidences of their battle with the elements and enemies; that is seldom the case with trees and shrubs that live for many years. Indeed, few such plants die of old age. In nature they finally succumb to the ravages of their insect, fungous, and bacterial enemies or to wear, tear, and breakage due to the "elements." Under cultivation it is these same factors that finally lead to their becoming unprofitable or unattractive, and the cultivator destroys them. In brief, they break down or are destroyed rather than wear out.

PROBLEMS

1. What kinds, types, or groups of plant disorders are likely to be localized within the plant, and what kinds or types are not so localized?

2. Are the kinds or types of plant disorders that are most likely to be localized within the plant likely to be similarly localized in the field or orchard? Why?

3. Are the causes of dwarfing of top general throughout or around the entire plant, or are they localized in or around only certain parts or organs? Explain fully.

4. Are the differences between slugs, caterpillars, and worms, as these terms are commonly used by the plant-grower, in appearance, or in the types of injuries to which they give rise?

5. Which would you fear most, borers or twig girdlers? Why?

6. Would you expect weevils to cause the fruit-grower, the grain-grower, the vegetable gardener, or the grower of ornamental plants the most damage? Explain.

7. Would you expect "locust" injury to be greater in an area of intensive agriculture or where grazing is dominant or in forested areas? Why? With vegetable or with fruit crops? Why?

8. How does a typical maggot differ from a typical caterpillar?

9. What reasons can you suggest for some of the symptoms due to aphid injury being attributed to the injection of toxins rather than just the extraction of juices?

10. Some groups or classes of fungi cause localized lesions; others give rise to symptoms that are more generally and evenly distributed over the plant; still others spread through the plant. Make a classification of the several groups from the standpoint of their localization or distribution on or in the plant.

11. Can you suggest any reason for rusts being more difficult to control than are mildews? Any reason for rusts being less difficult to control?

12. Would you expect cankers due to fungi or bacteria to be more readily distinguished from injuries due to insects or mechanical injury? Why?

13. How would you distinguish between *blighting* and *blasting* as these terms are commonly employed in speaking of plant disorders? In appearance? In causes? In organs or tissues affected?

14. How would you tell whether the small size of apple or pear tree, obviously very small for its age, was due to a dwarfing stock, drought, lack of soil nutrients, high water table, or a fungous infection of the roots?

15. What would you suspect as the cause or causes of the trouble if the lower leaves of herbaceous plants were turning yellow and falling off while the upper area remained dark green? If the upper leaves were turning yellow but showing no signs of falling, while the lower leaves remained normal in color? If all the leaves were becoming mottled yellow but not dropping? If all the leaves were taking on an even uniform yellowish cast but not falling?

16. Why is it necessary to destroy tomato worms, which eat the foliage only, when only the fruits are harvested?

CHAPTER XVIII

CONTROL OF PLANT ILLS

IN THE preceding chapter an attempt was made briefly to describe and discuss some of the more prominent groups or classes of plant disorders — groups or classes based more on the symptoms of distress exhibited by the plants than on the taxonomic relationships of the causal agents. In this chapter a similar attempt will be made to classify and discuss briefly the more commonly employed methods and materials that have been found useful in their control.

It has been customary in discussing control measures for the disorders of both plants and animals to classify them into two main groups — preventive and remedial. Obviously many such measures are of one or the other type. After caterpillars of some kind have started to eat foliage, spraying or dusting with a material that kills them is a remedial treatment, while the enclosing of a cherry tree in a bag or tent of cheesecloth or mosquito netting to keep birds away from the ripening fruit would be preventive. There are others, however, that are not so easily classified. The destruction of a plum tree carrying a virus disease is remedial from the standpoint of the disease on that tree and at the same time preventive from the standpoint of its possible spread to near-by healthy peach trees. Without any attempt to classify the different control measures in the one category or the other, some of the more important ones will be discussed here.

CONTROL BY ISOLATION

Of the several general methods of controlling plant pests one of the most effective and important seeks to isolate the plant, to keep it away from the pests or to keep the pests away from it, so that infestation or infection never takes place. Different procedures are employed in effecting such isolation, depending on the nature of the pest and on conditions. In some the isolation is extreme, in others the actual distance between infected and non-infected plants may be small, but nevertheless the barriers between them may be of such a nature that there is little likelihood of their being crossed. The inmate of a prison that is in the heart of a large city may be as effectually isolated from its people as though he were banished on some inaccessible island.

QUARANTINE

Quarantines are established and maintained for the purpose of preventing the spread of a disease or noxious insect, without necessarily any attempt to obtain control in the areas that are infested. Though the lines between quarantined and nonquarantined areas must be so drawn that actually they attempt to prevent spread from one farm to another, or even from one field to another, they are more likely to coincide with political boundaries, such as those between townships, counties, states, or countries. They call for (*a*) inspection of all vehicles or agents crossing the boundary lines which might transport articles that could possibly carry infection, (*b*) destruction or turning back of all infested or infected material, and (*c*) more or less continuous scouting of zones (narrow or wide, depending on conditions) on both sides of the established boundaries. This is to determine how close infection has become established and if by some chance it may have spread beyond the lines into theoretically non-infected areas. If this has happened, it calls for a prompt attempt at eradication in the "noninfected" areas or a shift in quarantine boundary lines. From their very nature quarantines are measures that can be employed only by governmental agencies, and the larger governmental agencies at that, such as the states or the federal government. They are always costly. They vary greatly in their effectiveness, depending partly on how rigidly the quarantine measures are enforced and even more on the nature of the agencies by which the insect or the disease is spread. It is obviously much easier to set up barriers against the spread of a soil-borne fungus than against wind-borne spores or an insect-carried virus.

Some quarantines, for example, those against the spread of the gypsy moth in New England and the citrus canker in Florida, have been reasonably successful. At least they have resulted in greatly retarding spread. Others, for example, those against the

Japanese beetle and the European corn borer, have been less successful, every season witnessing the pushing back of the quarantine lines and large additions to the infested areas. However, quarantines should not be regarded as complete failures, even though their boundary lines must be frequently changed. If they succeed in materially slowing down the spread of a parasite, thus affording opportunity for natural or artificial control measures to catch up with the pest or to be developed, they may be worth all that they cost, and this is the way most quarantine measures finally work out. Quarantine lines established at the seaboard or at other points of entry along international boundary lines are usually more easily enforced and more effective than those established within the borders of a country. Those living on the noninfested or noninfected side of a quarantine boundary line who thus obtain complete protection at public cost are usually in favor of the quarantine; those living on the other side who consequently obtain no protection and who may be subject to severe restrictions in the movement of their products to market are often not so enthusiastic.

ERADICATION

The objective of most insect- and disease-control measures is so to reduce infestation or infection in certain restricted (treated) areas that the damage resulting from them is negligible. Sometimes the objective goes still further and calls for complete eradication. This is true in some of the cases referred to in the preceding paragraph where a quarantine has been established, and infestation is discovered beyond the boundary lines of the quarantine. Prompt use of rigid control measures of different kinds may result in a complete stamping out of the new center of infection and restrict the pest to the areas where its toleration is accepted. Occasionally the same principle is employed in a more extensive area where there is general infestation or infection, usually with the aid of quarantine. As inspection and scouting indicate the continued absence of infestation from zones within the quarantine lines, they are moved in or contracted, and eventually the entire area may be freed from the pest. Such procedures are costly and not warranted in many cases, but there have been a number of successful instances — for example, the eradication of the Mediterranean fruit fly in Florida in 1927 to 30.

In recent years the term *eradicant sprays* has been applied to treatments with certain chemicals that are extremely toxic and that under favorable conditions may effect eradication in limited areas. More frequently, however, they result simply in drastic reduction in incidence of the pest and the term *eradicant* hardly applies.

NURSERY AND SEED-PLOT INSPECTION

An insect- and disease-control measure somewhat akin to quarantine is embodied in the nursery and seed-plot inspections that are in rather general use throughout the country. Most such inspection is carried out under regularly organized state agencies; some is sponsored by such semipublic agencies as seed- or crop-improvement associations; some is done by or for large corporate producers such as canning companies or even by individuals who are large-scale growers. The method consists simply in having the nurseries or seed fields thoroughly examined at suitable seasons by individuals who are acquainted with the pests and the disorders to which they give rise. Infected or infested plants are destroyed, or "rogued" out (or in some instances fumigated or otherwise treated to destroy all infection), and if infestation is general, the entire lot or nursery or field is condemned and not permitted to be used for propagation purposes. It is a type of quarantine "at the source" of infection. In general the nursery inspection of fruit-tree and ornamental stock has proven a very effective means of preventing the spread of both insects and diseases, but inspection of seed fields or plots has been less successful, owing to greater difficulty in the detection of certain seed-borne diseases. In any case, a certificate of inspection is not an absolute guarantee of freedom from all injurious insects and diseases; the inspection tag simply indicates that none were found by the inspector. The purchaser will do well to make his own examination before planting and then watch the plants for the appearance of any symptoms that may indicate trouble.

PRUNING AND ROGUING OUT DISEASED OR INFESTED PLANTS

The same type of inspection and roguing out of diseased or infested plants in the nursery row or in the seed field is equally effective in preventing the spread of the same pests after setting in the orchard, garden, field, or ornamental planting. Indeed, it is about the only practicable method of controlling the virus diseases, and it is equally useful in preventing the spread of some of the fungous infections, such as crown gall of the cane fruits and the Dutch elm disease. In general it is applicable to most of the disorders with which remedial treatment is ineffective and toleration is impracticable. In those instances in which the infection is still localized within the plant, as in the case of a blighted shoot or limb, a trunk or crotch canker, a knot or a gall on a root, pruning out and destroying the affected part will prevent spread just as effectively as will destruction of the entire plant.

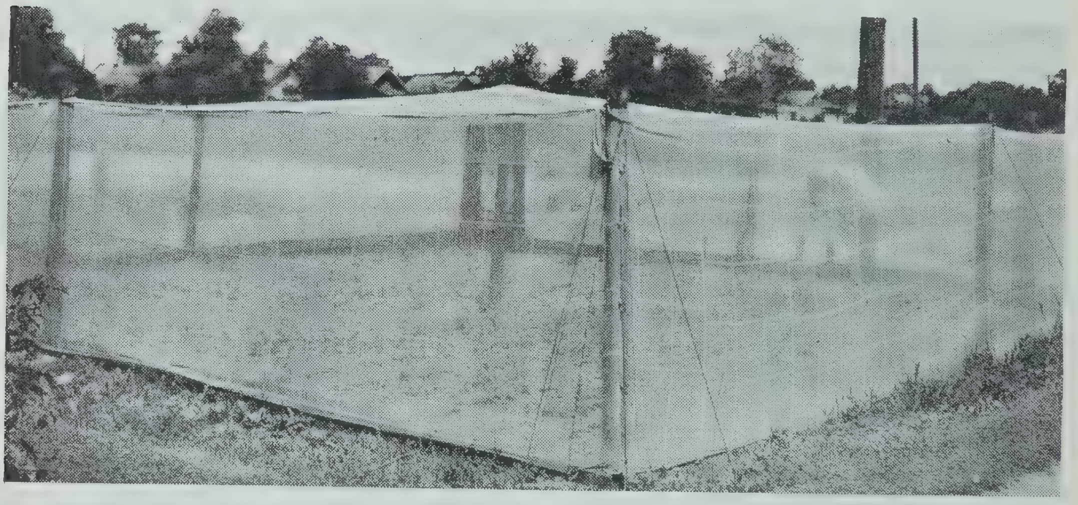


Fig. 170. A cloth house in which asters are being grown to protect them from the yellows disease which is spread by certain insects.

SCREENING AND BAGGING

The protection of plants within very limited areas from the attacks of certain pests by enclosing them within screens or cloth-covered structures of some kind amounts to a kind of extremely localized quarantine. It is a method commonly used in the commercial culture of China asters (*Callistephus chinensis*) to protect them from being infected with the "yellows" organism, which is spread by means of insects, and it is an effective way of protecting cabbage, cauliflower, and other seedlings while still in the seed bed from maggot infestation. A so-called "aster house" is shown in Figure 170. Essentially the same method of protection, in which the screen or covering is restricted to a single plant, is sometimes employed by amateurs to keep birds away from ripening crops of cherries (see Figure 171), grapes, figs, or blueberries. A still more restricted use of the same method consists in the bagging of individual fruits or fruit clusters — for example, melons and grapes — to protect them from pests of various kinds.

TRAP PLANTS

Though not strictly a method of control by isolation and in one sense the opposite of such a procedure, mention should be made at this point of the practice sometimes employed in the control of certain pests of growing so-called *trap* plants. These are plants extremely susceptible to attack by the pest in question — or at least far more susceptible than those of the kind that is being cultivated. The pests flock to these trap plants, which are then very thoroughly sprayed or perhaps destroyed, with an accompanying reduction of infestation of the crop plants. Thus mulberries are sometimes planted in or near cherry trees to attract the birds away from the cherries. Flea beetles will desert the eggplant and pepper if there is an opportunity to feed on the husk tomato (*Physalis pubescens*). A few scattered asparagus stems may be left to develop in the asparagus field to attract beetles while the other stems are being harvested at the usual time. The trap plants are then heavily sprayed with arsenicals.

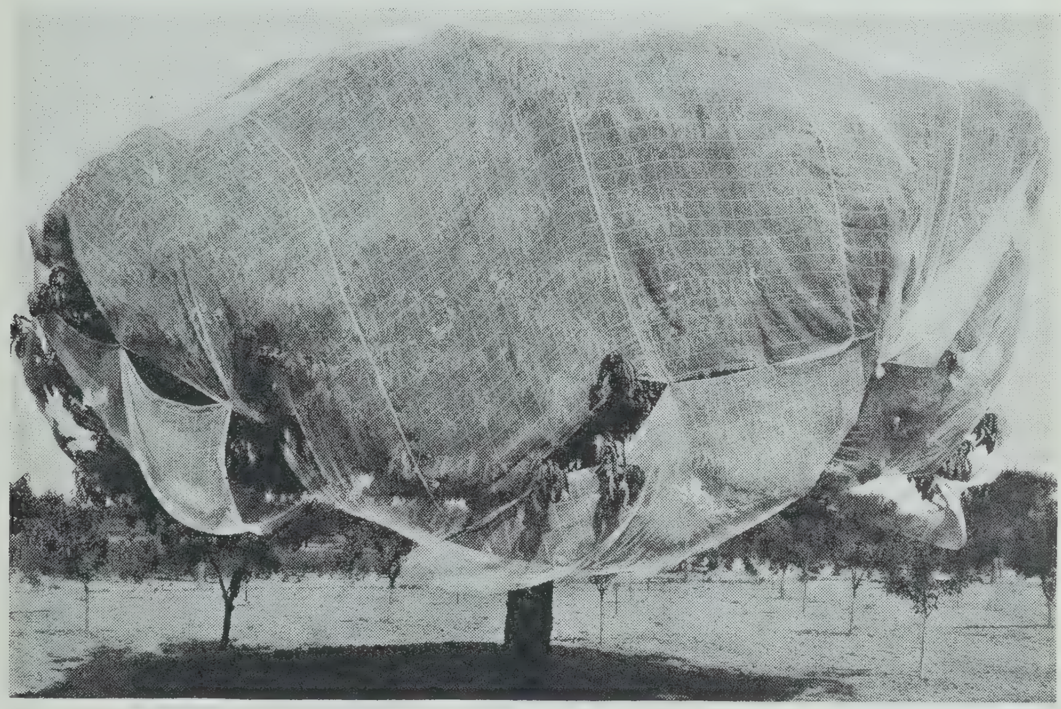


Fig. 171. A sweet-cherry tree enclosed in a coarse mesh-cloth bag to prevent injury to its fruits by birds. Pruning back the top of the tree has facilitated this method of bird control. Courtesy of the U. S. Department of Agriculture.

GRAFTING AND THE USE OF IMMUNE OR RESISTANT STOCKS

In the chapter on propagation one of the objectives of grafting was stated as being a means of reducing or even entirely avoiding losses from certain injurious insects and diseases. At one time the entire grape industry of Europe was threatened with ruin by the ravages of the *Phylloxera* or root louse, an insect that had been introduced from America and to whose attacks the roots of all European grape varieties (*Vitis vinifera*) are very susceptible. When it was established that these same European grape varieties grow satisfactorily when grafted on stocks of any one of several American grape species, whose roots are very resistant to *Phylloxera* attack, the problem was largely solved. In Australia the apple is commonly grafted on Northern Spy roots in order to reduce to a negligible amount damage from the woolly aphids, root-infesting insects. Losses from root, crown, trunk, and crotch infection with the fire-blight organism (*Bacillus amylovorus*) can be largely avoided in the pear by top-working the desired varieties into the limbs of such resistant stocks as Old Home (*Pyrus communis*) and *P. calleryana*. In some instances the well-informed grower can obtain plants that have "resistant" roots; in others he must first obtain the resistant stock and himself graft them over to the desired varieties. In either case it is a procedure that not only provides effective control of certain pests but that usually is the most economical method of control, for once the plant is well established on the resistant stock, no further thought need be given to that pest.

CONTROL BY PARASITES

In discussing quarantines as a method of controlling plant pests the statement was made that sometimes their value lies mainly in slowing down spread so as to give parasites a chance to catch up with the insect and bring about natural control. Parasites probably play a far more important role in the control of most insects than is generally realized. Evidence to this effect is furnished: (1) when a new pest is introduced from some other area, and it multiplies and spreads very rapidly for a while and then gradually subsides in numbers, and (2) by the occasional epidemic proportions attained by some pest already well established, apparently resulting from a lack of balance between host and parasites, followed in due turn by its almost equally quick subsidence, presumably due to restoration of balance between parasite and host. So important are parasites in the control of many insect pests that their collection, rearing, introduction, and dissemination have become a regular part of the entomologists' program of control for a new pest or for certain sections or areas where the parasites have not yet become well established. Biological control includes both predators and forms that work within the bodies of their hosts, together with a number of *entomogenous* fungi. For the most part introduction of parasites is the problem of state entomologists, plant boards or commissions, or other public agencies, who are concerned with general rather than localized control, but in some cases purchase and release of parasites on one's own farm are entirely practicable as an aid in the strictly local control of some insect. The oriental peach moth, an insect attacking ripening fruits of many kinds and of widespread occurrence, is a good example of a species more effectively controlled by parasites than by the more standard methods of spraying and dusting.

CONTROL BY CULTURAL METHODS

No less important than control of pests by isolation is control by cultural methods. They seldom if ever result in eradicating a pest from an infected area or even in preventing its natural spread as do quarantines, but they often are effective in reducing numbers. With their aid it is often possible to obtain two thirds or three fourths or perhaps almost a full crop, where otherwise there would be crop failure. Furthermore, with certain plants or crops and for certain pests they constitute the only practicable methods of control.

SANITATION

Most important of cultural means in insect and disease control is the combination of practices that are comprehended in the word *sanitation*. Many of the most serious of plant pests are carried over from one crop or season to the next on plant residues — stubble, stems, leaves, decaying fruits, seeds, etc. The plowing under or burning of such debris destroys many insects and spores and goes far toward reducing infection of the following crop. Prunings almost invariably harbor insects (especially borers) and should be promptly destroyed. Codling moths and other insects pupate beneath the rough bark scales on the limbs and trunks of mature apple trees, and control is greatly aided by scraping off and destroying the loose bark. Some of the pupae are directly killed by this treatment, and others are exposed to the action of contact sprays. Abandoned or much neglected orchards constitute a source of infection for near-by well-cared-for plantations and should, if possible, be destroyed. The roots of grasses furnish the favorite food of the larvae of June beetles, wire worms, and a number of other insects, and their control is very difficult, if not impossible, without at least occasionally breaking up the sod and placing the land under cultivation for a period. Other insects, such as the plum curculio and the apple maggot, though they may not feed on grass roots, winter over in or under artificial mulches or the vegetation supplied by sod. Their control, likewise, is greatly facilitated by thorough cultivation. The grasses, weeds, shrubs, and trees in fence rows and in adjoining wood lots and waste areas not only similarly afford hibernation quarters for insects, but in many instances serve as alternative feeding grounds or hosts for the pests of the crop or ornamental plants. In this way they function as perennial sources of infection and infestation, veritable breeding quarters for the pests in question. Jimson weed (*Datura stramonium*) is host to a virus that causes a mosaic disease of the cucumber, cantaloupe, and other cucurbits; the tent caterpillar feeds on the wild cherry (*Prunus pennsylvanica*) as readily as on the apple and pear; the hawthorn (*Crataegus*) is as much a favorite with the San Jose scale as are the peach and the quince. Good sanitation calls for a thorough clean-up of these waste places, a destruction of all debris and the eradication of all individuals of those species (herbaceous or woody) that serve as alternative hosts to the insects and diseases of the neighboring cultivated plants. If, as in the case of the cucumber mosaic, other species serve as host plants, control may be very difficult or even practically impossible.

Refuse that is thrown out from grading and packing houses is certain to carry much infection. Unless buried, screened, or treated with some material to render it innocuous, it is sure to prove a center for the spread of both insects and diseases. Field crates, picking utensils, and other equipment used in fruit and vegetable plantations soon become more or less covered and impregnated with plant tissues and their juices. Molds and bacteria of many kinds find them good media in which to grow and sporulate, and they often become a very serious means of spreading disease. They should be frequently cleaned and disinfected. Similarly, the fumigation of storage shelves, bins, cellars, and buildings, or other treatment of their floors, walls, and ceilings, is a sanitary measure that is likely to yield good dividends in the form of reduced infection.

CROP ROTATION

Many insects and diseases feed upon or attack many kinds of plants. Others feed upon or infect only a single kind or perhaps several closely related kinds. Thus the Colorado potato beetle is principally a potato-eating insect, though it sometimes attacks closely related species such as the eggplant. The mildew of roses is found only on roses, the rust of hollyhocks only on hollyhocks, the aster yellows only on asters. If any one of these crop or ornamental plants is grown year after year in the same location, there is opportunity, under ordinary methods of culture, for the soil or the surrounding plants or places of hibernation to become more and more heavily infested or infected, with the result that the pest becomes increasingly difficult to control. By raising the crop in another location, while the first location is devoted to some other crop for a year or two, both crops will more or less escape infection. In due course of time after the disease or insect has been pretty well starved out in the first area, it can again be used for the crop in question. As a matter of fact one of the principal values of crop rotation is the aid it gives in the control of pests. In the case of facultative parasites — those that do not depend for their survival on a single kind of plant — crop rotation is not very effective as a control measure. Moreover, it is not a control measure that can be employed with perennial crop plants, such as asparagus, grapes, or tree fruits.

VARIETAL CHOICE — RESISTANT VARIETIES

In the case of most crop plants the grower can choose from among a considerable number of varieties. Many considerations influence his choice — size, hardiness, and productivity of plant; color, form, and fragrance of its flowers; quality, keeping quality, and shipping quality of its fruits; market demand and price obtained for whatever part is sold, to mention but a few. Varieties likewise differ in their susceptibility and resistance to insect and disease attack (see Figure 167). Few varieties of plums surpass the Green Gage in flavor, and few equal it in susceptibility to brown rot; few pears surpass the Flemish Beauty in quality, and few equal it in susceptibility to scab; few roses surpass the American Beauty in fragrance, beauty, and quality when it reaches perfection, but few are as sensitive to unfavorable environmental conditions, as susceptible to mildew and black spot, and as difficult to grow to perfection; few raspberries possess the delicacy of aroma and flavor coupled with the firmness of texture of the Cuthbert, and few are as susceptible to the mosaic disease. The grower who deliberately chooses to raise Green Gage plums, American Beauty roses, or Cuthbert raspberries should realize that his disease-control problem is perhaps twice as difficult as that of his competitor who is raising the Italian prune, the Templar rose, or the Latham raspberry. He may succeed, or he may meet disaster. Every grower should acquaint himself with the relative susceptibility of different varieties to the insects and diseases most prevalent under his conditions and give them, as well as other varietal characteristics, due consideration when making his choice.

INDIRECT CONTROL METHODS

Crop rotation, the use of resistant varieties or resistant stocks, and certain practices identified with good sanitation are indirect rather than direct methods of combatting insects and diseases, at least in the sense that no attempt is made to destroy them. The effort is directed toward avoiding or evading them. The method is so effective in many instances that special attention should be called to it. For instance, the control of certain rusts (for example, the apple) that have alternate, or at least different, host plants is extremely difficult if sole dependence is placed on spraying, while destruction of one of the host plants automatically eliminates infection of the others. The principal carriers of virus diseases are insects, certain specific viruses often being spread by only one or a few closely related species of insects. Control of the virus is most readily obtained by control of its insect vectors. Thus the bacterial wilt and mosaic diseases of cucumbers, melons, squashes, and pumpkins are spread by the striped cucumber beetle, and in many instances the indirect damage that it causes is much greater than the direct damage due to its feeding. Poisoning the beetles automatically reduces spread of the bacterial wilt and mosaic.

It has been observed that ground moles very seldom cause trouble in lawns that have been treated with lead or calcium arsenate for the control of the Japanese beetle. The arsenicals likewise poison the June-beetle grubs, and the moles, not finding the beetle, their favorite food, is present, will seek other feeding grounds.

AIDING RECOVERY

Try as one will, with the aid of all the insect- and disease-control measures known, it is impracticable to keep crop or ornamental plants entirely free from insects and diseases of all kinds. Theoretically it might be possible to afford them such complete protection, but it would cost more than the plants themselves would be worth. A certain amount of insect infestation and disease infection must be expected and tolerated. What is called *good control* or *commercial control* simply holds this infestation and infection down to certain practicable limits that are set in part by the nature of the pest, of the host plant and by environmental and economic conditions. Light or sometimes moderate infestation or infection does not necessarily mean that the plant or the crop is ruined or even that it is seriously injured. The slightly blemished plant and its product may have considerable or even full market or other value. Not infrequently one sees oranges whose rinds have been roughened and russeted by the attacks of scale and other insects labeled "Russets" and sold at marked-up prices because of their alleged greater scarcity or higher quality.

In many instances the most practicable method of dealing with some pest is to employ no direct control measures but instead so to cultivate, irrigate, fertilize, or otherwise care for the plant that it will largely outgrow the effects of the infestation or infection and produce a good crop in spite of it. There is hardly an ornamental tree, shrub, or vine of any kind whose leaves are not subject to some caterpillar, miner, roller, or slug attack in the course of the season. In the great majority of cases, however, the damage is small, and if the plant is made to grow vigorously, no spraying is necessary, and the limited damage will not be noticeable. The trunks, stems, and branches of the lilac are subject to scale-insect attack, but one of the best ways to combat them is to fertilize and cultivate the bush so that their weakening influence will be more than compensated for. Limited defoliation of the peach tree by the leaf-curl fungus will cause no permanent, and very little temporary, injury if it is forced into strong vigorous vegetative growth by proper soil management methods. The same statement applies to many other infections. Recovery from early-season attacks is usually more complete than from those that come late in the season.

STOMACH POISONS

In the preceding chapter on "Plant Pests and the Injuries Caused by Them," it was stated that from the standpoint of the way in which they ingest their food insects may be classified in one or another of two main groups — those with chewing and those with sucking mouth parts. Those with chewing mouth parts may be readily killed with stomach poisons if the poison can be placed where it will be eaten. This is usually readily accomplished with most chewing insects that feed on foliage or on the surfaces of stems, flowers, or fruits. On the other hand, wood or stem borers, leaf miners, insects that feed on roots, and certain others cannot be easily poisoned. If the feeding habits of the insect are such that a stomach poison can be placed where it will be eaten, poison usually is the preferred method of control for, compared with other classes of insecticides, stomach poisons are relatively inexpensive, and it takes only very small quantities to kill.

ARSENICALS

Materials containing arsenic in one form or another have long been the most commonly used, the least expensive, and the most satisfactory stomach poisons. Paris green and London purple are the two that have been in use for the longest time. Paris green, an acetoarsenite of copper, is still employed in the control of the Colorado potato beetle in preference to most other materials. However, often it causes considerable spray burn to tender foliage, and it does not have very good sticking qualities when applied to smooth glossy leaves; consequently lead arsenate and calcium arsenate have taken its place for use on most fruit and vegetable crops and likewise on ornamentals. Many other arsenic-containing compounds have been tried, and most of them are effective enough as stomach poisons, but most of them likewise cause more or less injury to foliage or fruit. Lead arsenate and calcium arsenate are commonly used at the rate of one to three or even four pounds to 100 gallons of water when applied as a spray or at the rate of one pound to five up to twenty pounds of some inert diluent when applied as a dust. The strength or concentration depends on the kind of plant that is being sprayed and on the kind of insect that is to be destroyed. Most caterpillars and slugs are readily controlled by sprays containing two pounds of an arsenical to 100 gallons of water, but rose "bugs," blister beetles, the Japanese beetle, and many other resistant species require the stronger concentrations.

POISON BAITS

The term *poison bait* is applied to a stomach poison which has been mixed or combined with some other material that not only serves as a diluent but that because of smell or taste attracts insects that otherwise would not be likely to eat the poison. Such a bait in which bran is the principal diluent but which may also contain small quantities of molasses or sugar and perhaps traces of banana oil or other attractant and in which an arsenical poison is the killing agent is in common use for the control of cutworms in the garden and for grasshoppers under field conditions. Poison baits are also used for the control of field mice in orchards, moles in lawns, and for a number of other pests in other places, though in these cases strychnine, red squill, or some other toxicant may be used as the stomach poison, and carrots, apples, wheat, corn, or some other food material as the carrier.

Furthermore, poison baits are not limited to use against chewing insects and rodents. So called *bait pots* containing a stomach poison dissolved in a liquid medium that also contains some attractant are often suspended in orchard trees, gardens, or elsewhere to attract moths and some of the other sucking insects. In view of the fact that the poison is in liquid form, the moths can ingest it and are promptly killed, or the pot may be so constructed that the insects are trapped once they have entered it. In any case they are destroyed. Arsenicals to which has been added molasses, sugar, or some other attractant and which is then sprayed on plants may be lapped up by insects, such as flies, with sucking mouth parts, incidental to the flies' consuming the attractant. Such combinations may be classified with propriety either as stomach poisons or as poison baits. They are among the most effective control measures for a number of pests that as adults are flies with sucking mouth parts, and whose larvae are typical maggots.

CONTACT POISONS

As just explained in the preceding paragraph there are some insects with sucking mouth parts which feed on the surface of leaves or fruits that are effectually combatted by means of stomach poisons. Most insects of this type, however, cannot be poisoned in that way. For them there is a series of materials that kill by contact and that are known as contact insecticides. They include a number of oils that, upon coming in contact with the insect's body, spread over its surface and close its breathing pores, thus smothering it. They also include a great diversity of materials containing toxicants of different kinds that, upon touching the insect, paralyze some of its nerve centers or act in other ways upon other vital organs or processes.

OIL SPRAYS

Among the most effective and least expensive of the contact insecticides are emulsions made from a number of oils. The pure oils themselves are extremely effective killing agents for insects, but most of them are likewise toxic to plants, and consequently they must be diluted to make them safe to apply. Dilution is effected by first making them into emulsions in which they are uniformly dispersed (usually in water) with the aid of soap or some other emulsifying agent. In the case of many oils relatively stable, concentrated emulsions can be prepared that may be kept more or less indefinitely and then be diluted with water whenever wanted for use. In others the oils are inclined to separate out from the dispersing and emulsifying agents or media upon standing, and consequently they must be prepared each time just before using. The concentrated or stock emulsions usually contain from 30 to 95 per cent of oil by volume or weight and for application are diluted so that the spray as it goes on the plants contains from less than 1 to as much as 3 or even 6 per cent of actual oil. The amount depends on the kind of insect that is to be destroyed, the time of year when the application is being made, and the relative susceptibility to spray injury of the host plant that is being treated.

Oil sprays constitute the standard control measures for most scale insects and a number of other groups, such as mites, psyllids, and "red bugs." In the higher concentrations they are also effective ovicides and very useful in the control of aphids on certain plants.

Because of their toxicity to plants, the higher concentrations of oil sprays are usually applied only during the dormant season. Lower concentrations of oil sprays are often used during the growing season to destroy less resistant insects or to aid in the spread and adhesion of other spray materials. Most of the oil sprays applied during the growing season, however, are made of more highly refined oils or prepared by methods different from those used in the preparation of emulsions intended for dormant season use. They are often called *summer* oils.

Mineral oils, of the type commonly called lubricating oil with a viscosity of 100 to 240 seconds and 60 to 70 per cent unsulphonated residue are used in the preparation of most emulsions that are intended for dormant season use. Different emulsifiers, dispersing agents, stabilizers, and methods of preparation are employed, depending on the specific purposes for which the spray material is intended. The so-called *summer* oils used for spraying orchards during the growing season are highly refined mineral oils with a viscosity up to 85 seconds and 92 to 100 per cent unsulphonated residue. Oils of organic origin, such as fish oil, lemon oil, and pine oil, are commonly employed in making emulsions intended for use on greenhouse plants, as they are generally less toxic than those of inorganic origin. Some of the organic oils — such as fish oil, linseed oil, soybean oil — are used in low concentration (for example, one pint in 100 gallons of spray) as stickers in orchard sprays.

SOAPS

Soap is not only an emulsifying agent for oils that are used as insecticides, but itself is an efficient contact poison. This is due both to the oil or fat and to the base or alkali that is used in its manufacture, principally the former. Its insecticidal value varies considerably with the kind of oil or fat that it contains, fish-oil soap being especially effective. As a rule soap solutions are comparatively harmless to plants and strong concentrations may be used if they are rinsed off after a short time. They are especially valuable for the control of sucking insects on house plants.

ALKALIS AND CAUSTICS

In colonial days and likewise in the early days of commercial fruit-growing in America the standard method of destroying scale insects, mites, and other insects on the trunk, crotches, and main branches of trees was to apply lye, made by leaching wood ashes, with a brush or broom. It was effective and is still used by a few amateurs in their home orchards.

An entirely different caustic material that came into rather general use in its place at about the turn of the present century was a mixture of several compounds of lime and sulphur that at that time was generally called a lime-sulphur or sulphur-lime *wash*. It had been in earlier use as a sheep dip and was made by heating together stone lime and sulphur in the presence of water. Modifications of the formula for and methods of the preparation of this material has given us what we now call a lime-sulphur *mixture*. Like the earlier *wash* this is not a simple mechanical mixture of lime and of sulphur, but a complex mixture of a considerable number of chemical combinations of calcium and sulphur, that as freshly prepared or purchased in the market is very caustic. Properly diluted to a so-called *winter strength* it is used as a dormant-season spray on many plants for the destruction of scales and insect eggs of many kinds. Some of its constituents are strong reducing agents, and it has a very caustic or corrosive effect.

NICOTINE

Of the many plants from which insecticides have been prepared, tobacco (*Nicotiana tabacum*) is the most important. Powders made from the ground-up leaves, petioles, and stems of this plant or liquid sprays made from steeping these plant parts in water have long been used in the control of sucking insects of many kinds. The active ingredient contained in all these tobacco preparations is nicotine, a very effective insect poison when used in proper concentrations and possessing the virtue of being nontoxic to most plant tissues when used in these same concentrations. Were it not for the fact that they are relatively expensive, as compared, say, to the arsenicals, and that they soon lose their toxicity (through vaporization of the nicotine) upon exposure to air, tobacco sprays or dusts would probably be used much more extensively than they now are. As it is, however, they are the most effective and commonly employed sprays for aphids, leaf hoppers, and a number of other groups with sucking mouth parts. For many years nicotine has been available in the form of concentrated extracts — usually about 40 per cent nicotine sulphate by weight with 60 per cent of some inert carrier — and these are now used almost exclusively in place of the crude plant residues. Some idea of the extreme toxicity of nicotine to insects is obtained when it is stated that one pound of Black Leaf 40 — a standard 40 per cent concentrate of nicotine sulphate — to 100 gallons of water makes an effective spray for most aphids. This amounts to only one part of the toxicant to 1,000 parts of water, a 0.1 per cent concentration.

PYRETHRUM, HELLEBORE AND QUASSIA

Pyrethrum, as it is obtained in the market, is the powdered flower heads of a plant (*Chrysanthemum cinerariaefolium*) that is closely related to the garden chrysanthemum. The supply at one time came largely from Persia and Dalmatia, and consequently it was often known as Persian or Dalmatian insect powder. More recently a domestic supply has been developed. *Hellebore*, once in common use but now largely supplanted by pyrethrum and rotenone, is the powdered rootstocks of a tropical plant (*Veratrum album*) that belongs to the *Simarubaceae* family. *Quassia* is the name given to an insecticide obtained from the wood of two other tropical plants, Jamaica quassia (*Picrasma excelsis*) and Surinam quassia (*Quassia amara*). The active principle or toxicant of pyrethrum is pyrethrin, of hellebore and quassia, veratrine and quassin, respectively. All three materials are sold in powdered form and applied either as dusts (sometimes just as purchased without any dilution, sometimes after mixing with some inert diluent such as flour, air-slaked lime, gypsum, or even road dust) or as liquid sprays in which one part by weight is mixed with 50 to 100 parts of water. All three, like nicotine, are generally classed as contact poisons for they kill by contact, though they likewise serve as stomach poisons if they are eaten. Like nicotine, too, they soon lose their strength upon exposure to air and must be kept in airtight containers. Pyrethrum and hellebore are especially valuable in the control of both chewing and sucking insects on fruits (such as currants and gooseberries) and vegetables (such as cabbage and cauliflower) that may require treatment shortly before harvest. They leave no residue that would be poisonous to people eating the products, as would the arsenicals, and their residues leave no objectionable taste, as does nicotine. Quassia has never been used as widely as pyrethrum or hellebore, but has long been employed in the control of aphids on hops.

ROTENONE

The powdered roots or crushed tissues of a number of plants belonging to the legume family have been used for centuries in some parts of the world as fish poisons. When thrown into the water these materials temporarily stupefy the fish and cause them to come to the surface where they can be easily caught. Only recently have these substances been extensively tried out and used as insecticides. Now they rank among the more important of the contact insecticides and are taking the place of such materials as hellebore, quassia, and pyrethrum.

Tissues of a considerable number of plants of the legume family possess fish-poisoning properties, but those belonging to two genera, *Derris* and *Lonchocarpus*, are the most potent. From the fact that plants belonging to the first of these two genera constitute the main source of this poison, it is often known as *derris*. There are a number of more or less closely related toxicants that are obtained from these plants, but of them all rotenone seems to be the most important, and consequently that term is used in a broad sense to include all of them. Most of the species of *Derris* whose roots are of marked insecticidal value are shrubs, woody climbers, or trees native to Southeast Asia. Most of the species of *Lonchocarpus* that are valuable as insecticides are native to tropical South America.

Actual rotenone content of *Derris* roots varies greatly, from less than one to 12 or 15 per cent, depending largely on variety. Commercial extracts are made, containing from two to 50 per cent. For spraying purposes these materials should be diluted according to the concentration of the extracts and the resistance of the insect to be killed. For instance, many aphids are killed by 0.002 per cent concentration, while the Mexican bean beetle, one of the more resistant species, requires ten times that concentration.

MISCELLANEOUS TOXICANTS AND ACTIVATORS

The word *toxicant* has been used a number of times in the preceding discussion of various insecticides to refer to specific constituents of more or less complex substances or mixtures, constituents on which their insecticidal value largely depends, even though in terms of percentage they may be a very small part of the substance or mixture as a whole. Nicotine is the toxicant in the many insecticides made from tobacco, and rotenone is the toxicant in *Derris*. In some of the oil sprays insecticidal value is correlated much more closely with specific oil fractions than with total oil content.

Other toxicants, some synthetic, others isolated or derived from the purification of natural products, have been developed during recent years. Some of these are being used alone, some to mix with or reinforce other sprays. Thus the addition of very small amounts of dinitro-hexyl-cresol or of dinitro-cyclo-hexyl-phenol to a 2 per cent dormant-season oil spray may step up its value as a scalicide or ovicide to a point that otherwise would require a 6 per cent oil concentration. In these particular instances the material itself is a toxicant and functions on its own account as a contact poison. Toxicants are more commonly used with contact than with internal poisons. In still other instances the addition of certain substances that themselves have little or no insecticidal value to certain insecticides substantially increases their effectiveness. Thus the addition of some alkaline material such as sodium carbonate or caustic potash to a nicotine spray results in a quicker release of the nicotine and the consequent killing of a higher percentage of the insects. In this case the material functions simply as an *activator* of the insecticide. Another illustration of activators is the addition of small amounts of pyrethrum to rotenone.

FUMIGANTS

A third group or class of insecticides is known as *fumigants*. They are materials containing relatively volatile substances that are toxic in vapor form. Some of these materials likewise classify as stomach or contact poisons under certain conditions or when combined with certain diluents or inert carriers. Thus, as just explained, Black Leaf 40 is a preparation consisting of 40 per cent by weight of nicotine sulphate and 60 per cent of inert material. As such, when properly diluted, it is applied as a spray and functions as a contact insecticide. Nicotine is also available in other forms and combined with other carriers so that upon the application of heat the toxicant itself is quickly released as a vapor or gas, is distributed by air currents and acts as a fumigant. Furthermore, there are some fumigants that are used in the control of fungi or bacteria rather than as insecticides.

CYANIDES

Probably the most extensively used and certainly one of the most deadly fumigants is hydrocyanic acid gas. It is usually generated from the cyanide of potassium, sodium, or calcium. It is obtained from sodium and potassium cyanides by dropping these materials in acids, generally hydrochloric or sulphuric. The chemicals react violently, and the gas quickly diffuses throughout the space in which it is confined. It is used principally in the fumigation of greenhouses, storage houses, or other buildings that have become infested with insects of various kinds and for scale and other insects on citrus and other trees which can be covered with a tent of such construction that though not gasproof it is comparatively gastight. Hydrocyanic acid gas is released somewhat more slowly from calcium cyanide by scattering the crystals or powder on the damp walks of greenhouses, or by placing it in the burrows of moles, gophers, and other animals.

Most cyanide fumigation is done at night when the foliage is dry, the stomata are closed, the temperature is not so high as in the daytime, and there is less wind blowing to force or suck the gas out of the rooms or houses being treated. If the compartment is fairly tight one ounce of sodium or potassium cyanide will give off enough gas for the fumigation of 1,000 cubic feet of space. Great care must be exercised in hydrocyanic acid gas fumigation to keep people away from places where they will be exposed to the fumes, for these are as deadly to the higher animals as to insects.

CARBON BISULPHIDE

Another material that has long been used as a fumigant is carbon bisulfide. It is fairly volatile and is especially valuable in fumigation of weevil-infested seeds and small storage rooms. It is sometimes employed to destroy moles and gophers by placing in their burrows. An ounce or two poured on a large ant hill will kill most of its inhabitants. Its two main disadvantages are its offensive odor, making it disagreeable to handle, and its inflammability. Care must be exercised to keep it away from all fires and sparks.

PARADICHLOROBENZENE AND RELATED MATERIALS

Paradichlorobenzene has recently come into rather general use in the treatment of the peach-tree and a number of other borers.

A small mound of soil is drawn up around the base of the tree, smoothed down, and then a layer of the p.d.b. crystals is placed on this mound surrounding the tree and out from it an inch or so, this layer in turn being covered by a little soil. Vaporization of the toxicant takes place gradually, and the fumes penetrate not only the soil of the mound but the burrows of the borers in bark and wood of trunk, crown, and roots, and the borers themselves are killed by them. This fumigant is not safe to use on peach trees under four years of age, because of possible injury to bark and cambium, nor is it satisfactory for apple-tree borers. It works best when soil temperatures are reasonably high.

Ethylene dichloride has recently been made available in the form of an emulsion that can be diluted with water and poured on the trunk and crown of borer-infested trees where it functions much as does paradichlorobenzene. It has somewhat wider applications than does this latter material. Generally it has been considered less toxic to plants, though there are instances where it has caused serious injury to them. In view of the fact that different strength concentrated emulsions are sold by the trade, care should be exercised to dilute them accordingly.

BARRIERS, TRAPS, GLUES, AND REPELLANTS

Among the most effective control measures for certain insects and animal pests of other kinds are a number of types of mechanical or physical barriers and repellants. Possibly some of the measures already discussed under the headings of quarantines and screening might well be classified as the erection of barriers. There are, however, many others.

MECHANICAL PROTECTORS

Protection of flower beds and borders of shrubbery from cats, dogs, and other animals by means of wire screens or fencing or other mechanical barriers has always been practiced and is probably the surest and best means available. The use of so-called *tree protectors* made of galvanized wire screen (Figure 98) or of wood veneer or even of several thicknesses of paper to keep rabbits and field mice away from their trunks and crowns and of bands or collars of cardboard or tar paper about the stems of newly set tomatoes, cabbage and other plants to keep away cutworms (Figure 172) are but extensions of the same idea. The long bare trunks of newly set, high-headed ornamental trees are often spirally wrapped with a tough, crinkled, and perhaps chemically treated paper to prevent borers from egg deposition or otherwise gaining entrance and also as a protection against sun scald.

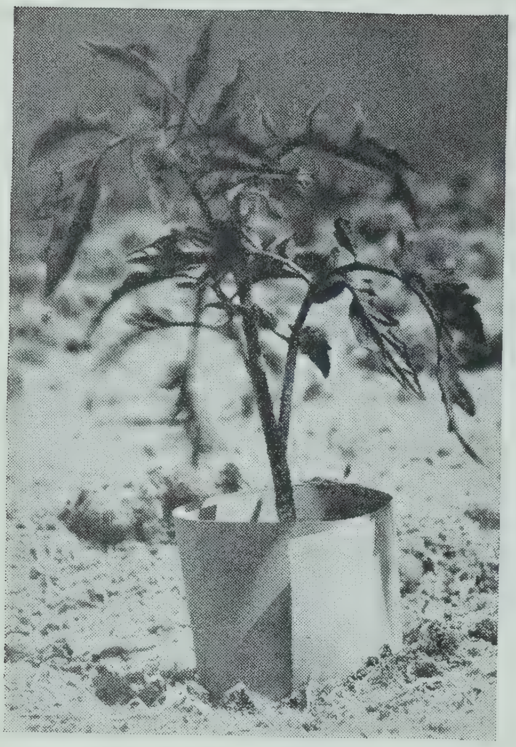


Fig. 172. A newly set tomato plant that has been provided with a collar of tarred paper to protect it from cutworms.

Furrows are sometimes plowed around or across fields to help slow down the advance of army worms. Bands of loose cotton are often tied around the trunks of trees or vines in such a way as to turn back climbing cutworms or other climbing insects. Equally or even more effective barriers are made by smearing or painting narrow bands of a grease or of some sticky substance such as "tree tanglefoot" over or across which climbing insects are unable or unwilling to go. Indeed the "banding" or "tanglefooting" of trees and vines is standard procedure in many northern orchards and vineyards.

TRAPS

Though traps are used for catching many animals, particularly mammals, trapping is not an important control measure for the pests of cultivated plants. Rabbits and field mice can be trapped, but are held in check more readily by other methods. On the other hand trapping has long been and still remains the most common method of destroying moles in lawns.

Insect traps of many kinds have been designed but on the whole have not found much favor in the control of field, orchard, or garden insects. Bait pots or bait traps have been mentioned as sometimes used for sucking insects. Light traps attract many night-flying insects and, if provided with electrically charged wires, may kill large numbers. Their practicability is in some doubt, in view of original and maintenance costs.

PASTES AND GLUES

Some of the small insects, such as red spiders and thrips, that are very resistant to ordinary contact insecticides and fumigants, may be controlled fairly readily by spraying with a water solution of paste or glue. As it dries, the insects are stuck fast to the leaves, stems, or other organs on which they are feeding and soon die. The plants can then be syringed with water to remove both the adhesive and its entrapped insects. Ordinary bill poster's paste is low in cost and very satisfactory for this purpose, though other adhesives are effective. This control measure is most commonly used for red spiders and thrips on various ornamental plants of the garden and greenhouse.

SYRINGING

Syringing has just been mentioned as being employed in connection with the use of adhesives in insect control. Often syringing alone is used as a control measure. This is entirely practicable in the greenhouse and garden where water under pressure is available and with plants infested with red spiders. Many of the insects are killed and many others are knocked off. Some of the latter find their way back to the plants, however, and frequent syringing must be resorted to if it is the only control measure that is employed.

REPELLANTS

A number of materials that have little or no value as poisons are nevertheless effective in the control of certain pests by acting as repellants. Some of these materials possess an offensive odor; others evidently are avoided because the insects do not like their taste. The adult flies that lay the eggs for cabbage and onion maggots avoid plants that have been recently sprayed with a carbolic acid emulsion; flea beetles of many kinds avoid foliage that has been sprayed with Bordeaux mixture; rabbits refuse to eat the bark of fruit trees painted with an alcohol-resin mixture. A substance that is offensive to one species is not necessarily offensive to another. Thus the resin-alcohol mixture just mentioned as a repellant for rabbits does not repel field mice.

The *scarecrow*, formerly so commonly seen in newly seeded fields and gardens and in cherry orchards approaching harvest, is to be classified as a bird-repelling device. The fact that it is less used than a generation or two ago does not mean that it is any less effective than formerly, only that better control methods have been found.

The discharge of guns and the use of various noise-making devices, often employed in cherry and other orchards as the fruit is ripening to frighten away birds are modern versions of the repellant idea.

FUNGICIDES

Materials used for the control of fungi, yeasts, and molds are called *fungicides*. Unlike many of the insecticides which are employed to kill pests after they have infested or attacked the plant, fungicides are applied primarily with the objective of keeping their spores from germinating or their mycelial threads from entering the tissues of the host plant. They are essentially preventive rather than remedial, though the superficial infections of certain kinds may be destroyed before they have a chance to spread. In most cases, however, little or no control can be obtained after the plant tissues have once been invaded.

Though there is a large number of materials that have fungicidal value, most of those in common use are copper-containing or sulphur-containing compounds or mixtures. This is due partly to the relatively low cost of these materials and partly to their high degree of toxicity to most fungi.

COPPER-CONTAINING COMPOUNDS

Many of the compounds of copper with other elements are very toxic to fungi. Many of these same compounds are likewise toxic to the tissues of the host plants and consequently cannot be used for spraying. Probably the most widely used copper-containing fungicide is Bordeaux mixture, so-called because its value in disease control was first discovered near Bordeaux, France. It is made by bringing together water solutions or suspensions of hydrated lime (calcium hydroxide) and bluestone (copper sulphate). The two interact, and a blue, complex, gelatinous copper-lime mixture or combination is formed. Though this gelatinous material will eventually settle out, it remains in suspension a long time and may be sprayed on plants to whose surfaces it adheres tenaciously upon drying. It is very slowly soluble, but nevertheless soluble enough so that it kills the mycelium and spores of fungi with which it comes into contact, or it prevents their germination. Concentrations vary from two to ten or twelve pounds of each of the two ingredients to 100 gallons of water, depending largely on the particular fungus whose control is sought. Bordeaux mixture is preferred to sulphur-containing materials for spraying pears, grapes, potatoes, and many other crops that regularly require fungicidal applications. This is because on the whole it is less toxic to foliage.

Many variations or modifications of Bordeaux mixture and of copper-containing compounds have been tried, and some of them are preferable for use on certain plants or under certain conditions to the standard Bordeaux that has just been mentioned. Several of these have appeared on the market under different trade names. These materials are copper oxychlorides, basic copper sulphates, copper aluminum silicates, copper oxides, and other combinations. They are as effective in the control of some fungous diseases as is Bordeaux and show less of a tendency to increase the rate of transpiration of the plant.

SULPHUR-CONTAINING COMPOUNDS

Elemental sulphur in the form of a finely ground powder is itself a very efficient fungicide. Its value in this form depends in considerable measure on the size of its particles.

Particles of the size found in "sulphur flour" or "flowers of sulphur," the forms in which it is usually sold by druggists, are comparatively large, do not adhere well to foliage or other plant surfaces, and are of rather low fungicidal value. Ground to much smaller sizes, and in many cases mixed with small quantities of wetting agents to make it more readily dispersed in water, sulphur flour is sold under various trade names that are semidescriptive of their character, for example, *atomic sulphur*, *wettable sulphur*, *micromatic* or "*mike*" *sulphur*, *colloidal sulphur*. These specially prepared products are much more readily and evenly distributed over plant surfaces; they adhere well; and they are effective fungicides. They cause less injury to foliage and fruit than most of the copper-containing compounds and than some of the other sulphur-containing compounds to be mentioned later. They are especially useful in the control of peach diseases, the foliage of that fruit being particularly susceptible to spray injury.

Almost any of the powdered sulphurs dusted on the surface of the soil or sand of beds, benches, flats, or pots in which seedlings are being started or cuttings rooted will prevent the spread of "damping-off" fungi.

The *lime-sulphur* mixture, mentioned earlier in this chapter as one of the caustic contact insecticides, is likewise a very effective fungicide, and it is commonly used for that purpose as a dormant season spray for the control of peach leaf curl. When employed as a dormant-season fungicide it is usually at the same concentration as when used as a dormant-season insecticide and serves in both capacities, but if control of peach leaf curl only is the objective, half that concentration is adequate. Diluted so as to have from one fifth to one tenth the concentration as when employed as a dormant-season spray, lime-sulphur is used as a growing-season fungicide on many plants — including apples, plums, and cherries.

Both Bordeaux mixture and lime-sulphur leave visible residues on foliage and fruit that are sometimes objectionable, especially in the case of ornamentals which are often valued largely for their smooth glossy leaves. The finely ground elemental sulphur sprays leave less of a noticeable residue, but even that is sometimes objectionable, particularly on such plants as roses that are being grown for cut flowers. Another sulphur compound, *potassium sulphide*, may be used in such cases. It leaves very little residue and is an efficient fungicide for the control of surface mildews.

BACTERICIDES

There are a number of ways in which bacteria resemble fungi and likewise a number of ways in which bactericides resemble fungicides. As a matter of fact most of the fungicides possess some bactericidal value, and most of the bactericides possess some fungicidal value. Some of the materials classified here as bactericides are used in preference to any of the fungicides that have been mentioned for the control of certain fungous diseases. Steam sterilization of soil is one of the most effective methods of ridding it of both bacterial and fungous infection. The two bactericides most commonly used in the control of plant diseases are formaldehyde and various mercury-containing compounds.

FORMALIN

Formalin is a water solution of formaldehyde gas, of which it usually contains approximately 40 per cent by weight, as it is purchased in the market. Its principal use in plant-disease control is for the treatment of seeds, bulbs, corms, etc. before planting to destroy organisms carried over from season to season on these structures. When used for this purpose the seeds or other parts are soaked for varying periods (one to three hours at room temperature and depending on kind of plant, or perhaps only a few minutes if at a temperature of 50° C.) in a formalin solution in which the 40 per cent concentrate has been diluted with 200 to 250 parts of water. The treatments are usually given immediately before planting. Otherwise the seeds or bulbs must be spread out to dry, after which they are subject to reinfection. Though formalin is classed here as a bactericide, in accordance with usual practice, most of the seed- and bulb-borne diseases for which it is used are in reality due to fungi or *Actinomyces* rather than to bacteria.

Formalin is also used for the sterilization of soil in cold frames, hot beds, greenhouse benches, and for seed pans, flats, and other containers. For this purpose it is diluted with 50 to 100 parts of water, and enough of the solution used to wet thoroughly the soil or its containers.

CORROSIVE SUBLIMATE

Corrosive sublimate, mercuric chloride, or bichloride of mercury, as it is variously called, is used more extensively than any other material as a sterilizing agent. In a 1 to 1,000 dilution it can be employed for treating seeds, bulbs, tubers, etc. for seed-borne diseases, as explained above for formalin. Several commercially prepared germicides employing mercuric compounds as their toxic agents are in common use for the disinfection of seeds, bulbs, etc. Among the more prominent of these are semesan, a mercuric chlorophenol sulphate, and ceresan, an ethyl mercuric chloride. Calomel, mercurous chloride, used at the rate of three ounces to 1,000 square feet of surface, or better still a mixture of one and one-half ounces of calomel and one and one-half ounces of corrosive sublimate, is often employed in the treatment of dollar spot, brown spot, and snow mold on bent-grass lawns. At a 1 to 1,000 concentration corrosive sublimate is also valuable for sterilizing pruning or other wounds and tools that have been used in cutting out diseased tissues. This is important when pruning trees that are infected with such diseases as the fire blight of pome fruits and the bacterial gummosis of cherries which are very easily spread by such means. It is a satisfactory material for dipping or spraying orchard crates, lug boxes, and other containers that are used over and over again and to spray on the surfaces of bins, shelves, and storage rooms to rid them of decay organisms.

ZINC CHLORIDE

Zinc chloride is not a bactericide that is commonly employed in the control of plant diseases, but it is of proven value for one that has been difficult to control and consequently is mentioned here. If a 50 per cent solution (zinc chloride, alcohol, hydrochloric acid) is painted on the surface and edges of cankers of the fire-blight organism, it will penetrate the bark tissues and kill the bacteria that are working in the cambium layer. This method of control is much simpler and less costly than the one that has been generally employed, namely cutting out and destroying the infected tissues and then sterilizing both wounds and tools.

HERBICIDES

In the culture of many crop and ornamental plants weeds cause more trouble than insects and diseases together. Crop rotation, use of clean seed, deep plowing, thorough and frequent cultivation, the destruction of noxious weeds in and about cultivated fields before they mature their seeds, and other practices identified with good sanitation are the measures upon which the grower must mainly depend for their control. There is, however, a number of chemicals that can be used under certain conditions to reduce the competition that weeds afford the crop plants and the cost of their control by usual weeding methods. Among the many materials that have been tried as herbicides certain chlorides, chlorates, sulphates, arsenites, phenols, and cresols have been found the most promising.

Common salt, sodium chloride, has long been used successfully to destroy weeds in driveways, walks, and other places where no plant growth of any kind is wanted. Applications of the salt crystals are made at the rate of from a half pound to a pound to a square yard. Calcium chloride, which is in common use in road maintenance for keeping down dust, may likewise be used for weed control on drives and walks. One application of either of these materials is usually enough for an entire season, and there are likely to be some hold-over effects the second year. Neither should be used on land that is to be cropped the following season.

Sodium and potassium chlorates dissolved in water at the rate of one or one and one-half pounds to a gallon are toxic to the foliage of most plants, and there may be enough penetration of the soil to kill crowns and roots as well. They are useful in the treatment of small patches of such species as bindweed, Canada thistle, and poison ivy, where temporary destruction of all vegetation, except trees whose roots are deeper and whose foliage is not covered by the weed spray, is not objected to if the offending weed can be eradicated. Productivity of treated soil may be somewhat lowered for a year or two in humid areas and often much longer in arid or semi-arid sections.

Several of the arsenicals, too soluble and too toxic to plants to use as insecticides, are fairly effective herbicides. These are white arsenic or arsenic trioxide and sodium arsenite. Either of these materials dissolved (to the extent possible) in water at the rate of one pound to fifty gallons will "burn" most foliage and tender shoot growth. They do not, however, possess any apparent advantages over the chlorates or phenolic compounds.

Dinitro-hexyl-cresol and dinitro-cyclo-hexyl-phenol solutions in which these toxicants are carried in concentrations of one part to 500 up to 2,000 parts, by weight, of water will destroy the leaves of many plants, if applications heavy enough thoroughly to wet the foliage are used. Several successive applications must be made actually to kill plants that have a considerable reserve of foods in roots or stems and that consequently are able to put out new growth after one and perhaps a second or third set of leaves has been destroyed. This is unnecessary with young seedlings in their first year. These materials possess the advantage over the chlorates and chlorides that insufficient amounts enter the soil to have a residual toxic effect on succeeding crops. For instance, they could be used to destroy poison ivy under trees and climbing over their trunks, without injury to trees or soil.

Copperas or iron sulphate is sometimes used as a weed eradicant in grain fields. Weeds of certain kinds with tender foliage — for example, wild mustard and charlock — are killed by concentrations that do not harm the foliage of the crop plants. It is applied as a spray, using a pound or pound and a half of the copperas to a gallon of water.

Though in no sense herbicides, there are certain conditions and practices relating to weed control to which attention may be called in connection with this brief discussion of materials sometimes used in their eradication. A weed has been defined as a perfectly good plant but one growing out of place where it is not wanted. If that is the case, it follows that it should be good practice to see that no place is provided for them and this is often best done by putting crop plants where weeds would otherwise find opportunity to grow. In more specific terms, this means that one of the best ways to keep weeds out of lawns is to have the ground literally covered with grass, using plenty of seed to start it and then reseeding often enough to keep it well stocked. Furthermore, it means providing favorable moisture and nutritive conditions for the grass to grow and thrive. In the sod orchard — and likewise in the lawn — it means further that if weeds become established they are kept under control by occasional, or perhaps frequent, mowing so that they never have a chance really to compete with the cultivated plants. Few weeds will thrive, and many will not survive, under close clipping. This principle of permitting or of making the crop plants crowd out the weeds, of course, does not apply to cultivated crops while *in the young seedling stage*, but once they are well started they are usually able to hold their own in the struggle for existence. Weeds must be rigidly controlled early in the season; then the crop plants will take care of them later.

COMBINATION SPRAYS AND COMPATIBILITIES

The preceding chapter briefly described and discussed a number of classes or types of plant pests and the characteristic symptoms or types of injury which they cause. This chapter has discussed certain methods and materials that are used in their control. Though in both cases only the more important have been mentioned, the numbers are large enough to give the impression that the problem of insect and disease classification and control is very complicated; that each and every kind of insect, fungus, bacterium, and virus has its specific preventive or remedial measure; and that the situation is well-nigh hopeless for any except the professional entomologist, pathologist, or horticulturist. Admittedly it is somewhat complicated; nevertheless, it is not so bad as it may at first seem for certain spray materials may be combined with others, and a single application made to deal with a considerable number of pests.

Perhaps the ideal, especially for the amateur, would be to have a single combination that could be used for all of them, a kind of "shot gun" application, but that has not yet been, and perhaps never will be, realized.

COMPATIBILITY OF SPRAY MATERIALS

The first essential in the combination of different spray materials is that they are compatible; that is, they should make a good physical mixture and not react chemically with each other so as to destroy or reduce the effectiveness of one or both of the ingredients or cause greater injury to the plants to which they are applied. The "trial and error" method has pretty well established the combinations that may be safely made. The arsenicals may be mixed with any of the two main groups of fungicides — those containing copper or sulphur compounds. They may also be mixed with most of the contact insecticides derived from organic sources, such as nicotine, pyrethrum, and rotenone, though when spraying with a contact insecticide there is seldom any need of using a stomach poison at the same time. In general, sulphur-containing fungicides do not combine well with the oil sprays, and oil sprays being contact insecticides, there is no point to adding the organic contact poisons to them. Bactericides are used for a different class or type of pests and under different conditions than either the insecticides or fungicides, and there is little occasion for combining them. From their very nature, fumigants would not be combined with other classes of control materials. In reality, therefore, the three principal compatible group combinations in use are: (*a*) stomach poison + fungicide, (*b*) organic contact poison + fungicide, (*c*) stomach poison + organic contact poison + fungicide. Since each group includes a number of materials, a rather large number of individual combinations is possible. For information on specific compatibilities and incompatibilities the individual should consult the spraying calendars, mentioned later in this chapter, or follow the directions of the manufacturers of the materials he is using.

CORRECTIVES, WETTING AGENTS, SPREADERS, AND STICKERS

In one sense any material, not of insecticidal or fungicidal value itself, that is used along with another that possesses such value, to reduce its toxicity to the plant, improve its physical condition, or otherwise alter or improve it may be considered as a corrective agent. Thus, while it is the copper sulphate in Bordeaux mixture that gives it its fungicidal value, lime must be used with it to prevent injury to plant tissues. In this instance the *corrective* enters into chemical combination with the toxicant. In other instances lime or other materials are used in the spray that may or may not enter into chemical combination but that in one way or another serve as protective agents for the plants against otherwise toxic effects. Thus zinc sulphate and lime or iron sulphate and lime are commonly added to arsenical — sulphur-spray combinations applied to peach trees to reduce "arsenical injury" to foliage, fruit, and twigs. Spray manufacturers often use such correctives in the preparation of materials sold in a ready-to-dilute form. If they are of such a nature that they tend to prevent or delay either the physical or chemical breaking down or change of the spray material as it is applied to the plants — a change that may result in injury to foliage or fruit — they are often called *stabilizers*.

The leaves and fruits of many plants are covered with a waxy or powdery cuticle that water alone will not readily wet and to which the spray materials alone or dissolved in water will not closely adhere. In some instances addition of a little soap or glue to the spray will give it better wetting and spreading qualities. Resin-fish-oil soap has been especially recommended for this purpose. During recent years a number of so-called *wetting agents* and *spreaders* have been developed that have been found very useful in improving the spreading and wetting quality of certain sprays.

Still other materials, called *stickers*, are sometimes added to spray materials to increase their adhesiveness and reduce or retard their removal by rain and other weathering processes. Summer oils, in low concentrations, are perhaps the most efficient of the stickers. They are more commonly employed with the arsenicals than with contact insecticides or fungicides. Stickers of this type must be used with caution, or too much objectionable residue will remain on the fruit at the time of harvest, perhaps necessitating wiping, brushing, or other removal measures.

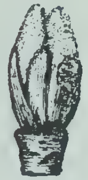
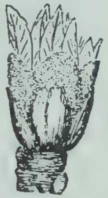
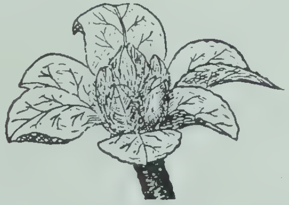
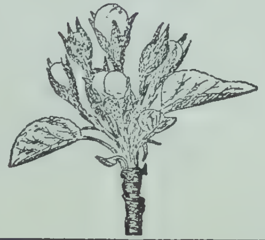
SPRAY PROGRAMS, SCHEDULES, AND CALENDARS

An essential in the successful control of any pest by means of spraying is to have the material distributed on the surface of the organs to be protected when, or better still, just before infection may take place or feeding begin. Fumigation necessarily comes a little later when the insects have hatched and are present in a form or stage in which they can be reached by the lethal gas, though any considerable delay after that may result in much damage. In any case, timeliness is very important. It is especially important with fungi and with insects which feed within plant organs and tissues rather than on their surfaces. Delay of a few days, or even a few hours, in the application of a fungicide at some critical period may permit its spores to germinate and its mycelium to penetrate stomata or otherwise gain entrance to tissues where it cannot be reached by any treatment. Thus, if a peach leaf-curl spray is applied a few days too late to prevent infection of opening or swelling buds, it may just as well be omitted entirely for the season, for the damage will have been done, though the resultant defoliation may not take place until some weeks later.

If timeliness is of first importance in determining the effectiveness of a given spray application, thoroughness and completeness of coverage are second. Chewing insects feeding on the surface of leaves or fruits only partly coated with stomach poisons will eventually come to and eat the poisons and be destroyed; on the other hand sucking insects not actually touched by contact poisons at the time of applying may escape uninjured and fungi may gain ready entrance through spots or areas not coated by a fungicide and then spread widely within the plant. A fully protected plant is one that is completely covered. More failures in the control of pests by spraying are due to faulty coverage than to faulty timing.

For the control of certain disorders — for example, the leaf curl of peaches — a single thorough and timely application of the proper material is all that is required. No further trouble from it need be expected before another year. Other disorders — slugs and mildew on roses, the Colorado beetle and "blight" on potatoes — are a constant menace from the beginning to the end of the growing season. Protection against them can be provided only by applications repeated often enough to keep the old and new foliage at all times covered with the spray. Such a series of applications is often referred to as a spraying *program.* It is comparatively simple, though it may call for a considerable number of applications in the course of the season. Many of the vegetable crops are protected by a spraying *program* of this type.

APPLES

STAGE OF GROWTH	APPLICATION	MATERIALS		TO CONTROL	EXPLANATIONS
	1. **DORMANT.** Complete before green tips appear.	Lime-sulphur, 12½ gal. in 100, tar, tar and oil or an oil spray. Refer to Sections 6 and 18 to 29 for specific instructions.		Scale insects, mites and leaf rollers. Lime-sulphur will control scale. Oils will control scales, mites and leaf rollers. Tar sprays and D N sprays will control aphids. Tar and oil, and D N and oil will control aphids, mites and scales.	The dormant application of oil is necessary for the control of mites and leaf-rollers and will also control scale. Lime-sulphur may be used if scale only is to be controlled. Refer to Sections 18 to 29 for specific instructions.
	2. **DELAYED DORMANT.** Apply in a well developed greentip stage, when leaf tips are ¼ to ½ inch in length.	Lime-sulphur, 2½ gal., lead arsenate,† 3 lb., nicotine sulphate, 1 pt., and water to make 100 gallons.	**These applications are the most important for scab control.**	Scab, aphid, and bud moth. Omit the nicotine sulphate if a dormant application of *D N or tar, tar and oil has been made.	This is the best period for the control of aphid, if this has not been effected by dormant applications, and the lime-sulphur that is necessary with the nicotine will prevent early infection of apple scab. Lead arsenate is partially effective against bud moth. Refer to Sections 47 and 48 for special instructions for the control of aphids.
	2a. **PRE-PINK.** Begin soon after the delayed dormant condition and complete as soon as possible.	Lime-sulphur, 2½ gal., lead arsenate,† 3 lb., and water to make 100 gallons.		Scab, curculio, and bud moth. If aphids have not been controlled by this time nicotine should be added as satisfactory aphid control cannot be expected later than the pre-pink application.	Apply the pre-pink on the more susceptible varieties and on all varieties when conditions seem very favorable for scab development, or in seasons when bud development is spread over a long period. Still another application for scab control between the pre-pink and pink applications may be desirable under extreme conditions.
	3. **PINK.** Begin to apply as soon as most of the buds have separated in the clusters and complete before the blossoms open.	Lime-sulphur, 2 gal., lead arsenate, 3 lb.,† and water to make 100 gallons.		Apple scab, curculio and other chewing insects.	This application is important for scab control. The lead arsenate is of value for the control of chewing insects, as well as increasing the fungicidal value of the lime sulphur. Do not use lead arsenate after the blossoms begin to open. Bees may be poisoned and pollination of early bloom reduced.

THIS SCHEDULE WILL MAKE RESIDUE REMOVAL NECESSARY.

† The use of lead arsenate is unnecessary in all pre-blossom applications, but at least one spray is advisable prior to calyx.

	4. PETAL-FALL (CALYX) Should be made when most of the petals have dropped and after bees have quit working in the bloom.	Lime-sulphur, 1½ gal., lead arsenate, 3 lb., nicotine sulphate, 1 pt., and water to make 100 gallons. Nicotine sulphate may be omitted if red bug is not prevalent.	These are the important applications for codling moth control.	Scab, codling moth, curculio, other chewing insects and red bug. Wettable sulphur may be substituted at this time.	Spraying should not begin until most of the petals are off and there are no bees working in the trees, but should be completed as soon as possible. Refer to Section 49 for the control of red bug.
	5. FIRST COVER. Seven to ten days after petal-fall.	Wettable sulphur, 4 to 6 lb., lead arsenate, 3 lb., and water to make 100 gallons.		Codling moth, curculio, lesser apple worm and scab.	WARNING. IMPORTANT Govern use of lead arsenate during the summer by the prevalence of codling moth. Read carefully Section 4 and 41. If fruit is not to be washed, refer to Section 42.
	*5a. SECOND COVER. Seven to ten days after application 5.	Lead arsenate, 3 lb., zinc sulphate-lime (See Sec. 33), and water to make 100 gal.		Codling moth, curculio, lesser apple worm and scab. If apple scab is prevalent, the use of wettable sulphur may be advisable at this time.	
	*5b. THIRD COVER. Ten to fourteen days after 5a.	Lead arsenate, 3 lb., zinc sulphate-lime (See Sec. 33), and water to make 100 gal.		Codling moth, lesser apple worm and curculio.	
	*5c. FOURTH COVER. Two weeks after 5b.	Lead arsenate, 3 lb., zinc sulphate-lime (See Sec. 33), and water to make 100 gal.		Codling moth, lesser apple worm and curculio.	
	*6. SUMMER GENERATION. Exact time to be determined each year, usually about Aug. 1.	Lead arsenate, 3 lb., zinc sulphate-lime (See Sec. 33), and water to make 100 gal. Add wettable sulphur 4 to 6 lb. if needed for scab control.		Codling moth, curculio and scab.	The exact time of this application is determined by the Entomology Department and announcement is made through county agents.
	7. Two weeks after Application 6 and if necessary make one or two more applications at two weeks intervals.	Lead arsenate, 3 lb.		Codling moth and curculio.	

IF FRUIT IS NOT TO BE WASHED, REFER TO SECTION 42.

* If conditions have been especially favorable for development of apple scab and it has not been controlled, a fungicide may be applied in any of the cover sprays.

FIG. 173. Recommended spraying calendar for apples in Michigan.

For the proper protection of some of the fruit crops from their many insect and fungous enemies a somewhat more complicated spraying program is necessary. For instance, peach trees require a strong fungicide some time during the dormant season for the control of leaf curl, one or more applications of a stomach poison shortly after fruit setting for the control of curculios and other chewing insects, and finally one or more applications of a weak fungicide as the fruit is approaching maturity for protection against brown rot — and under certain conditions still other applications for other disorders. Such a program is often called a spraying *schedule* or spraying *calendar*. These schedules or calendars are not only different for different fruits and even for different varieties of the same fruits but for different sections or areas, depending on the relative prevalence of pests of different kinds. Thus, the one for apples in Michigan, reproduced in Figure 173, is in rather marked contrast to the recommendation given at about the same time in a bulletin of the North Dakota Experiment Station, which reads: "Orchards in North Dakota being small and widely separated, there is as yet less trouble from pests requiring spraying than elsewhere. Coddling moth, the insect causing wormy apples, is usually present but is fairly well controlled by one spraying with arsenate of lead within a week after the blossoms fall, using 1½ pounds of powder to 50 gallons of water." Schedules do not quite reduce spray applications to a set of rules, but they tend in that direction and materially simplify the whole question of choice of materials and timing for the grower. Such spraying schedules or calendars are prepared by investigators in the agricultural experiment station of each state and are subject to change from year to year as new insects and diseases are introduced, as those already established change in virulence, and as old control measures are improved or new ones are discovered.

For the amateur or inexperienced grower the recommended spraying schedule amounts to a set of rules to be followed as closely as possible. For the more experienced grower they serve more as a general guide, to be modified to meet special conditions as his own experience and judgment dictate. To illustrate: In the northeastern states the summer strength of the lime-sulphur mixture is the standard fungicide for the control of apple scab, though where or when infection is light, a wettable sulphur is preferred. While this particular chapter was being written, the author happened to talk with an experienced apple-producer one evening during the period when it was time to apply the so-called *ten-day spray* (about ten days after the petal-fall application). The grower remarked that earlier in the evening he had directed his hired man to spray the apple orchard the following day, using wettable sulphur if it did not rain that night but lime-sulphur if it did rain because a somewhat stronger fungicide would be needed.

SPRAYING VERSUS DUSTING

Some materials can be applied only in the form of liquid sprays, others only in the form of dusts or powders. Still others may be applied in both forms. There has been much controversy between advocates of spraying and advocates of dusting as to the relative value of the two methods of application. Probably neither method is to be regarded as best; both methods are useful, and each has its place. Certainly spraying has proven more effective than dusting for large trees. On the other hand, the airplane dusting of extensive areas of certain field crops and forest areas has been found practicable where liquid spray applications would be out of the question. In general, quicker coverage of large areas can be effected by dusting and more thorough coverage by spraying. Dust applications are less likely to stain foliage and fruit and leave excessive amounts of residue.

SPRAY INJURY

The toxic effect of spray materials on the leaves, fruits, and other organs and tissues of crop and ornamental plants has been mentioned repeatedly. Sensitiveness of some plants to spray injury is a factor of considerable importance in the control of their insect and fungous pests. For instance, there is some question as to whether the spraying of raspberries is practicable except during their dormant season, not because they are not troubled with insects and diseases or because those insects and diseases cannot be controlled by proper sprays, but because raspberry foliage is so susceptible to injury from most kinds of sprays. Consequently, in the bramble-fruit plantation roguing out of infected plants and other sanitary measures remain the principal methods of pest control. The skin of Jonathan and Baldwin apples is much more susceptible to russeting by sprays (Figure 174) than is that of McIntosh and Delicious. Greater care must therefore be exercised in the choice of spray materials, especially correctives, to use with them. Defoliation following certain sprays that have been used to control the leaf-spot disease of sour cherries has been only a little less severe than that caused by the disease itself in unsprayed orchards. As a matter of fact, decision as to whether to spray or not to spray has often amounted to a choice between the lesser of two evils, with control of insects or fungi by spraying being chosen as the lesser but with every effort being made to reduce the injury that it causes to a minimum by the use of correctives and sooner or later by the development of safer spray materials.

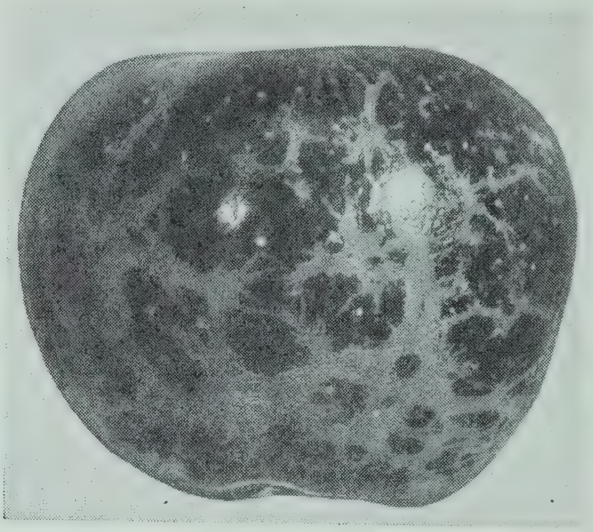


Fig. 174. A Baldwin apple with its surface russeted owing to the spray materials that were used.

SPRAY RESIDUE

Most spray applications leave visible residues on foliage, flowers, fruits, and other organs. Such residues on the leaves of vegetable crops used as salads or of ornamentals valued because of their foliage — and this includes a large share — may be very objectionable. In the case of fruit crops it makes little difference how severely the leaves are coated or stained, if the fruit itself shows little visible residue. To remove residue from leaves by means other than rinsing in water is impracticable and tightly adhering sprays cannot be removed in that way. Consequently, dusting is recommended in preference to spraying for such crops as cabbage, cauliflower, or even celery if an application of any kind is required shortly before harvest. The same condition holds for such fruits as currants and gooseberries that cannot be wiped, brushed or subjected to an acid-dipping treatment. On the other hand, excess spray residues on apples, pears, plums, and cherries may be removed by brushing or dipping in dilute acid, then rinsing in water and drying, and this has come to be common practice in many packing houses. Such treatment serves the added purpose of removing dust and dirt and often greatly improving the appearance of the fruit as well as removing all danger of possible toxic effects of lead or arsenical poisons.

PROBLEMS

1. Distinguish between infestation and infection, and give examples of each.

2. Certain aphids carry the virus of peach yellows and spread the disease from tree to tree. The disease may be controlled by sprays that destroy the aphids. Is this a preventive or a remedial control measure? Explain.

3. Explain how control by quarantine differs from control by seed plot inspection.

4. Some pests are controlled by the substitution of resistant for susceptible *parts*. Would this be more practicable as a method of controlling root or leaf disorders? Why? Disorders of herbaceous perennials or woody perennials? Why? Would it be more practicable in monocotyledonous or dicotyledonous plants? Why?

5. What is meant by the expression "bug fights bug," and what is its significance in insect control of cultivated crops?

6. How do you account for the fact that native wood lots or forest trees do not require spraying, or even the application of sanitary methods of insect and disease control, when neighboring orchards do?

7. What are the principal factors that determine whether an insect is best controlled by a stomach poison, a contact poison, or a fumigant? The host plant? The kind of mouth parts possessed by the insect? The plant parts or tissues on which it feeds? Or some other factor? Explain.

8. How does the action of winter-strength lime-sulphur on insects differ from that of an oil spray?

9. Explain the ways in which the action of toxicants, activators, and correctives resemble each other and also how they differ from each other.

10. Can you figure out any way in which a spray material might be effective in the control of a virus disease? Would you expect such a spray material to be a fungicide or an insecticide? Why?

11. Which class of spray material requires the most thorough coverage and which the least in order to provide effective control — contact poisons, stomach poisons, or fungicides? Why?

12. In general, would heavier and more frequent applications of herbicides be required to eradicate annual or herbaceous perennial weeds? Why?

13. At what time of the year or stage of the season's growth would an herbicide go the furthest or be most effective in the eradication of woody plants, such as poison ivy? Why?

14. In the case of an arsenical spray do you think that the addition of a wetting agent or a "sticker" would be the more likely to increase its value? Why? Apply the same question in the case of a contact poison of organic origin, such as nicotine, and in the case of a fungicide.

15. Copper-containing fungicides are generally employed to control leaf diseases on potatoes while sulphur-containing fungicides are generally employed to control leaf diseases on apples. How is this to be accounted for?

16. Would you be more likely to use a preventive or remedial treatment for worms in apples? Why? For plant lice on roses? Why?

17. Would you use oil sprays or arsenicals to control caterpillars on cabbage? Why? Scale on the trunks of trees? Why?

18. An old adage reads: "An ounce of prevention is worth a pound of cure." Does this apply more appropriately in the application of fungicides for the control of fungous diseases or of certain insecticides for the control of chewing insects? Explain why.

19. Which of the following materials are commonly used as preventive and which as remedial treatments in the control of orchard and garden pests: Bordeaux mixture, Paris green, Black Leaf 40, tree tanglefoot, carbon bisulphide? Explain each answer.

20. Name the three spray materials that you would consider most important for the amateur grower of vegetables, fruits, and ornamental plants always to have on hand to deal with outbreaks of insects and diseases, and explain why you have singled out these particular materials.

CHAPTER XIX

THE CULTURE OF ANNUALS

IN THE preceding chapters an attempt has been made to explain some of the more important influences on plants of certain features of environment, such as light, moisture supply, and nutrient conditions. The discussion, however, has been from the standpoint of their influence on plant functions or processes, rather than of the reaction of specific kinds or groups to them. On the other hand the plant-grower thinks less of processes and functions than he does of crops and cultural practices. It seems desirable, therefore, to call attention to some of the principles of plant growth as they apply to the culture of certain groups of crop and ornamental plants. The first of these groups that will be discussed here is the annuals.

There are so many different kinds of annuals; they belong to so many different genera and families; they differ so much in appearance and habit of growth that at first it might seem futile to attempt to group them together for the purpose of suggesting any cultural requirements that they may have in common. By definition, however, they are all characterized by a life span of one year or less. Most of them are propagated by means of seeds. Though there is an almost infinite amount of variation in seeding practices, in their methods of germination, and in the care that the young seedlings require, there are likewise a number of conditions that the planter must attempt to provide, and a number of things he must try to do, for all of them, if he is to obtain a good stand of plants, and they are to get off to a good start. Furthermore, as they grow to maturity most of them call for much the same basic differences in treatment that will promote the change from the vegetative to the reproductive phase.

SEEDING

SEEDING TIME

The time for sowing the seeds of annuals is governed principally by three factors or conditions: (1) when the product — be it root, leaves, flowers, fruits, or seeds — is wanted, (2) the length of time required for the development or maturity of these plant parts, and (3) temperature, in most cases temperature being the controlling factor in influencing rate of growth. Soil moisture supply, light intensity, and length of day are likewise influencing environmental factors with many species and varieties, but for the most part are subordinate to temperature. These several influencing conditions are interacting rather than completely independent. Thus, certain varieties of sweet corn are known as 90-day, 100- or 115-day kinds; similarly, we have 30-day, 40-day, and 60-day varieties of radish, 50-, 60-, and 80-day varieties of cosmos (*Cosmos bipinnatus*). These descriptive phrases simply mean that *under average conditions* the sweet corns require 90, 100, or 115 days from seeding to the maturing of "roasting ears"; the radishes require 30, 40, or 60 days from seeding to the development of full-sized, still crisp roots; the cosmos varieties require 50, 60, or 80 days from seeding to initial flowering. If temperatures are subnormal instead of average, the 90-day variety may require 100 or 105 or even more days to mature; if they are above normal, it may attain maturity in 85, 80, or even 75 days. If the gardener wishes to harvest edible ears of sweet corn about August 15, he seeds a 90-day variety about May 20, or a 100-day variety about May 10. If he wishes to harvest corn more or less continually between August 15 and September 15, he either can seed 90-, 100-, 110-, and 120-day varieties, about May 20, or he can seed a 90-day variety at intervals of five to seven days between May 20 and June 20. If he knows that temperatures in his location are characteristically lower than those where the variety in question is most at home, he may seed somewhat earlier (provided it is not too cool) and count on a 90-day variety taking 100 or even more days to mature, or he may employ an early or extra early variety (an 85- or an 80-day kind), if it is available, instead of an average variety. With kinds that are being grown in sections where the length of the average growing season is just about the same as the period normally required for the maturity of the crop in question, seeding is usually done just as early as weather conditions permit, in the hope that the crop may be harvested before the growing season is ended by a killing frost or some other limiting factor of the environment.

Should length of growing season be shorter than the period normally required for the growth of the plant, resort can be made to seeding in cold frame, hotbed, or greenhouse and then transplanting to the field or garden when conditions outside become favorable. Thus, in northern latitudes the growing season for tomatoes is often lengthened by some six or eight weeks, that of cantaloupes by four to six weeks, that of zinnias by three to four weeks. Similarly, extra early maturity of kinds that could ordinarily be matured outdoors from seeding in the field can be obtained by sowing the seeds indoors some four to eight weeks earlier than the outdoor seeding date and then transplanting, though the gain in earliness is considerably less than the four to eight weeks theoretically gained by the indoor seeding. In the course of this discussion, it is, of course, assumed that growing-season temperatures are such that the kind in question is reasonably well adapted to them and that it will grow and mature, provided that the season is long enough or that it may be sufficiently lengthened by starting the plants indoors and later transplanting to the field. No amount of artificial lengthening of the growing season by starting the plants in the greenhouse or hotbed would make possible the maturing of Sea Island cotton or the casaba melon in a New England or northern Michigan summer. As indicated in the chapter on "Temperature Relations of Plants," the time of seeding cool-season crops in a given section can be earlier by days or weeks than that suitable for warm-season crops.

In some sections and with some crops seeding date is determined in part by seasonal variations in the prevalence of certain insects or diseases. Thus relatively late fall seeding of winter wheat enables the young plants largely to escape attack by the Hessian fly, and early seeding of garden peas often results in less injury from aphids than would later seeding.

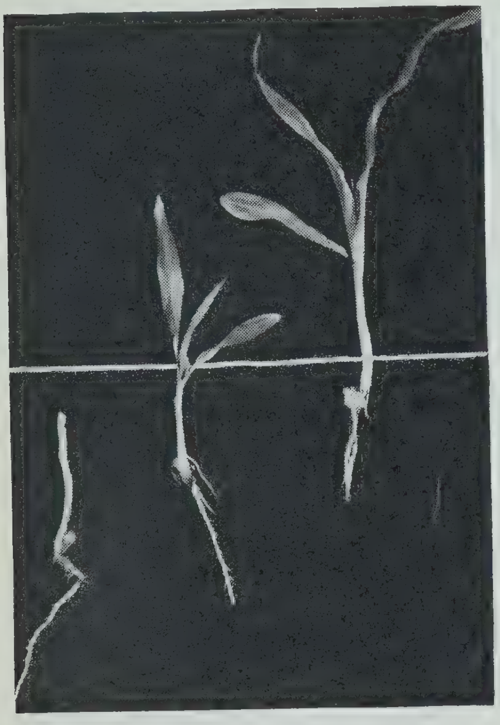
SEEDING RATES

The seeds of many annuals are "broadcast," that is, distributed as evenly as possible over the entire surface with the objective of obtaining a solid stand. This is true generally of the grasses, whether in the lawn, pasture, or meadow; of the so-called "small" grains; and of a large percentage of the vegetable and ornamental plants that are started in pans, flats, or beds in the greenhouse, hotbed, or cold frame. How thick the seeding should be depends on kind of plant, on viability of the seed, and on certain objectives which the grower has in mind. For instance, in the case of small grains what is wanted is a stand dense enough to cover the ground fairly well after the plants have stooled but not so dense that crowding results in shading out and killing any considerable percentage of the plants. In the lawn, pasture, and meadow complete coverage of soil is desired and hence a more dense stand. Usually this is accomplished by such a heavy seeding that as the plants grow and begin to crowd, many are shaded out and destroyed. Little thought is given to the loss of a half, three fourths, or even a larger percentage of the young seedlings. Indeed, this is to be expected if a dense turf is to be obtained quickly. On the other hand, a somewhat thinner stand is wanted in the greenhouse bed, bench, flat, or seed pan to enable the seedlings to attain *pricking off* or transplanting size without becoming "drawn" or spindling from too much crowding. This may mean spacing each way of a quarter inch or less in the case of celery and lobelia seeds and a half inch or inch each way in the case of tomato and cosmos.

With many other plants seeding is in rows or in hills. The rows themselves may be from a foot or even less to six or eight feet apart and the seeds may be dropped as close together as several to the inch or as far apart as three to six feet. For instance, lettuce and radishes are seeded in rows from a foot to two or two and one half feet apart, and it is not unusual for fifty or more seeds to be dropped to the foot. Sweet corn is seeded in rows three to four feet apart and the seeds average eight to twelve inches apart in the row. Watermelons are seeded in hills four to six or more feet apart in rows that are six to eight feet apart, several seeds being placed in each hill. The seedlings will later be thinned to not more than three or four, and sometimes to only two, to the hill, and the lettuce plants may be thinned to even a foot apart in the row, in the case of some of the large heading varieties. In any case seeding will be heavy enough to provide a surplus of plants so that by thinning a full, even stand can be obtained. Some thinning expense can be avoided by moderate or even light seeding, but this often results in too light and uneven a stand. Somewhat heavier seeding is employed on a very fertile soil than on one of lower fertility if plants of only a certain medium size are desired. Lighter seeding and thinner stands result in larger and more productive individual plants than heavier seeding and denser stands, but, except within rather narrow limits, are likely to result in lower total yield per square yard or per acre.

DEPTH OF SEEDING

The great majority of seeds, as distributed by natural agencies, are left on the surface of the soil where they are subject alternately to taking up moisture and to drying out. Many seedlings die before they ever become really established. Covering them, even with a very thin layer of soil or leaves or other debris, affords considerable protection against desiccation and enables a much larger percentage to complete the germination process and the seedlings to survive. Consequently, in the seeding of crop plants they are almost invariably covered, except in the case of very small seeds which are simply pressed into the soil, and then the whole seed pan or flat protected with a pane of glass or other cover so as largely to prevent the surface from drying out. Depth of covering is governed by size



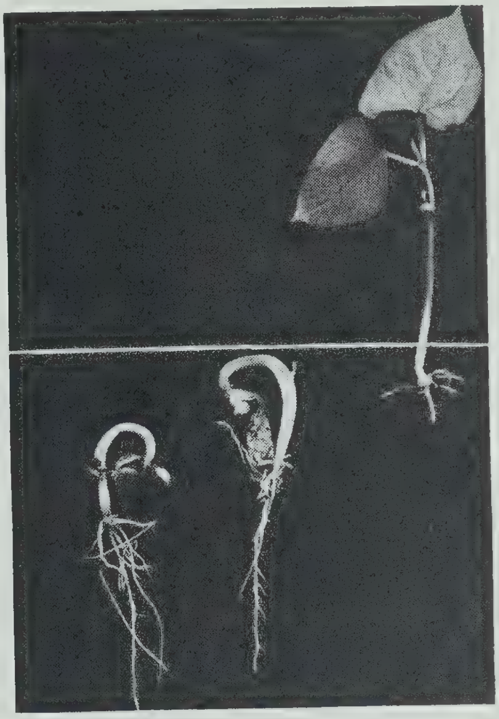


FIG. 175. (*Left*) Seedlings of sweet corn produced from seeds planted at the same time at depths of three, two, and one inches. Though it took longer for the seedling from the two-inch-deep seed to push its leaves above the soil level, it would probably catch up with the plant at the right. The seedling at the left would probably emerge above the soil, but it would require considerable time to overtake the other two. Compare with Figure 176.

FIG. 176. (*Right*) Seedlings of the garden bean produced from seeds planted at the same time at depths of three, two, and one inches. The one at the right emerged promptly. It is doubtful if the one at the left would ever reach the surface. The plant in the center might reach the surface, but it would require considerable time for it to catch up with the plant at the right. Compare with Figure 175.

of seed, method of germination, and character of soil. A walnut or chestnut seed can be planted much deeper than the seed of a radish or tomato. Seeds of sweet corn can be planted considerably deeper than those of the garden bean, which are about the same size, because the cotyledon of the corn grain remains in the ground when it germinates, while those of the bean must be pulled or pushed out of the ground. Some of the results of different seeding depths for corn and beans are shown in Figures 175 and 176. Seeds may be planted more deeply in a loose porous soil than in one that is compact and inclined to bake. In general, relatively shallow planting is preferable to deep planting where there is an abundant supply of moisture, as less of the seed's supply of stored food is required for the building of stem tissues that serve no other purpose than simply to raise the stem tip above the soil surface. On the other hand, where the surface soil is likely to dry out and remain dry for any considerable period following seeding, somewhat deeper placement is more likely to result in germination and survival. If seeds are planted shallow in a dry soil, and no rain follows or no irrigation water is applied, seeds may fail to germinate for days or weeks. Depth of seeding is likely to have very little influence on depth of rooting.

TRANSPLANTING

As pointed out in a preceding paragraph, annuals of many kinds can be successfully raised in sections where the growing season is too short for them when seeded in the open by starting them indoors and later transplanting to the field or garden, or if the growing season is long enough for them to complete their life cycle, they can be made to mature early by the same procedure. If the seed pans, flats, or beds are very lightly seeded the seedlings may be allowed to remain in them for transplanting to the field, and they are subjected to a single transplanting. More commonly, however, seeds are distributed so as to provide a heavier stand in the seed bed and a first transplanting, or *pricking off,* is given them while they are still very small, perhaps when they have produced only their first two or three true leaves (as distinguished from their seed leaves or cotyledons). At this first transplanting they are set rather close together, perhaps not more than an inch apart each way, or they may be put into very small ("thumb," or two-inch) pots. When they begin to crowd, they are again transplanted so as to provide them with more room, or they may be set into the field. Each transplanting serves as something of a temporary check on rate of growth and has a tendency to make the plant more stocky, the greater stockiness being due in part to providing more room in which to grow and in part to the check in rate of growth.

Pricking off and subsequent transplantings, as usually performed, disturb the soil about the roots and break some of the roots. The more severe the breakage, the more seriously is the plant checked at the time of transplanting. Even with very careful transplanting there is likely to be a checking that amounts to a week or more of growth, sometimes to two or three weeks, and, if most of the roots are destroyed in the transplanting process the plant may never recover. In other words, transplanting *per se* is not to be regarded as a useful practice in the sense that it causes the plant to grow faster or better than it would have had it not been transplanted. Indeed, it has the opposite effect and should be viewed more in the nature of a necessary evil with certain plants grown under certain conditions or with certain objectives — for example, to meet an early market demand. Thus field-seeded tomato plants attain larger size and yield heavier crops than transplants of the same varieties in sections with comparatively long growing seasons. On the other hand, where the growing season is short the transplants are able to mature a larger percentage of their fruits before being killed by frost, and they outyield the direct-seeded plants. Early seeding indoors followed by transplanting to field or garden may be advisable in a certain section with salvia, a late blossoming variety of aster, or late maturing variety of tomato; of questionable value with midseason kinds; and entirely unnecessary and undesirable with early maturing sorts. One advantage of transplanting is that for the early portion of the growing season, when weed control is usually most difficult, it concentrates a large number of plants into a small space where they can be cared for with much less labor than would be required were they scattered over the entire area that they are to occupy later in the season. In the greenhouse it effects a saving of valuable space. These advantages often more than compensate for the check in rate of growth caused by transplanting.

Care should always be exercised in transplanting not to disturb the soil and break the roots more than is consistent with reasonably rapid work. This is especially important in the final transplanting to the field or garden. To avoid undue disturbance of soil and breakage of roots it is considered good practice to have the soil very moist, though not wet, so that it adheres to the roots and so that, upon being pressed or squeezed, the soil mass sticks together without much crumbling. Under these conditions, it is possible to transplant with a ball of earth; fewer plants are lost; and there is quicker recovery. To compensate, at least in part, for the loss of some roots in transplanting, it is considered good practice to break or twist off some of the leaves. This reduces transpiration losses and helps tide the transplant through the critical period while new roots are being formed. Wherever possible, it is desirable to transplant just before a rain is expected or to water the newly set seedlings. Usually a single watering to settle the soil about the roots is sufficient.

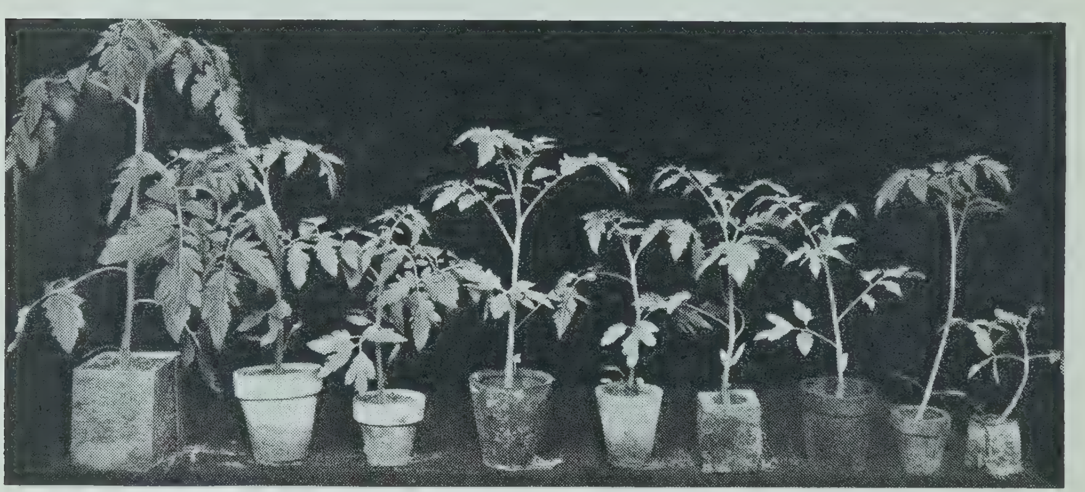


FIG. 177. Tomato seedlings of the same age but grown in different sizes and types of containers. The photograph shows the influence of both factors on size of plant. The slenderness of the two plants at the right is due to crowding.

Seedlings of a great many species transplant with ease, while those of certain others transplant with difficulty. Even a small disturbance of the soil about their roots and the breakage of a few roots check them so severely that they are very slow in recovering or may never fully recover. Sweet corn and the cucurbits are of this type. Where climatic conditions are such that these plants cannot be grown successfully without transplanting, they are often started in pots, plant "bands," or in inverted chunks of sod. A number of types of these transplanting aids are shown in Figure 177, which also shows their varying influence on amount and type of growth. When the seedling is nicely started, the sod is carefully moved so as to keep the roots intact, or the band or pot is removed without disturbing the soil mass or roots. Transplanting is thus accomplished with a large ball of earth, and there is no setback. In many of the northern sections cantaloupes, early tomatoes, and many flowering annuals are regularly started in this way.

REPOTTING

Seedlings that have been pricked off into two-inch pots usually are left in them for three to five weeks, by which time they will have become more or less pot-bound and have ceased growing. If "shifted" to larger pots, growth will be resumed and will continue until they again become pot bound, when a second repotting is called for. The growth rate of many annual plants is such that successive repottings are necessary every six or eight weeks, if continued growth and maximum size is desired. Size is under fairly complete control in the case of potted plants through the ability of the grower to restrict water and nutrient supply by growing in pots of different sizes.

HARDENING OFF SEEDLINGS AND TRANSPLANTS

Seedlings that are about to be transplanted from cold frame, hotbed, or greenhouse to the field or garden are usually *hardened off*. This consists in checking their growth for a few days, usually by withholding water or by exposing them to a lower temperature than they have been accustomed to, or by a combination of both methods. The result is a less succulent, tougher, harder, and often hardier plant that is better able to survive the shock of transplanting. Extreme hardening is seldom necessary or desirable, and there is little need of even moderate hardening in the case of seedlings that are to be kept in the greenhouse, hotbed, or cold frame after pricking off or transplanting, for hardening is essentially a gradual adjustment to unfavorable growing conditions, and under glass the conditions for growth usually remain as favorable after transplanting as before. Hardening is usually thought of as a process that primarily is for the purpose of accommodating the plant to a lower temperature and of actually making it more resistant to frost injury — in brief making it hardier. Hardening does have this effect on plants of many species, such as celery and cabbage, but it has little influence of this kind on others, such as the tomato or zinnia.

With them, however, it does afford some protection against drying out and distinctly aids in adjusting them to new and more unfavorable environmental conditions.

CULTIVATION AND WEED CONTROL

In the growing of many, if not most, annuals more effort is directed toward the control of weeds than to any other single feature of their culture, for it must be remembered that every weed is a competitor of the crop or ornamental plant for standing room, water, nutrients, and light. Weed control is effected largely by means of cultivation. Wherever possible the seed bed is prepared early enough so that a large percentage of the weed seeds germinate before it is necessary to seed or transplant the crop plant to the field. Under these conditions a single shallow cultivation just before seeding or planting the crop is more effective in destroying the young weed seedlings than several cultivations a little later when they have become well established. If preplanting cultivation is impossible because of the necessity of early seeding or transplanting, one or two post-seeding or post-planting cultivations while the weed seedlings are at a corresponding stage of development will serve very well in its place. The labor required to row cultivate an acre is considerably greater than that necessary for an all-over, surface harrowing.

No hard and fast rules can be given for depth or frequency of cultivation, though in general it should be frequent enough to keep the weeds under control, and this depends on the kinds of weeds and weed seeds present, the type of soil, and weather conditions. Depth of cultivation is influenced by the same factors and also by the frequency, for if cultivation is frequent enough to catch the seedlings in an early stage it need not be deep in order to root them out or cover them. On the other hand, after weeds have become well rooted, deep cultivation is necessary to tear them loose or cover them, and deep cultivation is likely to injure the roots of the crop plants, sometimes causing almost as much, or even more, harm than good. Other conditions being comparable, the shallower the cultivation can be and still control the weeds, the better. The guiding principle in most weed control is well stated in the old adage, "A stitch in time saves nine." If rainy weather or other conditions prevent the eradication of weeds in their early stage while the crop plants themselves are just getting started, it sometimes is more practicable to abandon the crop entirely than attempt to save it.

It has long been taught that cultivation is useful not only, or even not principally, as a weed-control measure, but as a means of reducing loss of water by evaporation and of aerating the soil and thus promoting certain desirable chemical and bacteriological processes. It doubtless has a desirable influence on certain biological changes in the soil, but its beneficial effect in reducing evaporation losses is now known to be negligible. It is valuable largely as a weed-control measure.

As indicated in this discussion, cultivation destroys weeds in two ways — by rooting them out so that they cannot obtain water and nutrients and by covering them with soil so that they have no access to light. This is essentially a smothering process. There are other methods of smothering weeds, the two most important being shading them out by crowding and by artificial mulches of different kinds. As mentioned in connection with the discussion of seeding rates, crowding out of weeds by heavy seeding of the crop plant is an effective method of weed control in the case of the small grains and such plants as are used for lawn-making. Mulching either with special mulching paper or with straw, grass, or crop residues is not employed as extensively with annuals as with some of the perennials, because it is relatively too expensive to use with crops that occupy the land for only a single year.

Except during their first year when their control presents essentially the same problem as that of annual weeds, most perennial weeds such as the Canada thistle and quack grass are deep rooted and provided with food reserves that enable them to push up a second, third, or even fourth lot of shoots, if the first are destroyed by cultivation. They are consequently much more persistent and require more frequent and generally deeper cultivation than do the annuals.

FERTILIZATION AND IRRIGATION

The basic reason for cultivation and for thinning or otherwise spacing annual plants is to remove competition of weeds, lessen that of other plants of the same kind and thus to afford each one an opportunity for its maximum development under the temperature, nutrient, moisture, and light conditions that exist. The objective in irrigation and fertilization is still further to remove the crop or ornamental plant from struggle with other vegetation for water and nutrient supply — indeed, to do away entirely with that struggle. If the soil is naturally very fertile, if rainfall is abundant and well distributed throughout the growing season, and if the soil is retentive, neither irrigation nor fertilization are necessary, and they may even prove harmful. Providing good soil drainage and preparing a deep seed bed are measures that serve to reduce the necessity of both irrigation and fertilization, for they promote deep rooting and tend to make available the moisture and nutrient reserves in a larger volume of soil. So handling the surface soil that there will be a maximum intake or absorption of the natural precipitation and a minimum of surface runoff similarly reduces the need of irrigation and fertilization. Proper rotation tends to even out over a period of years the draft of the crops on the different nutrients of the soil and postpones the time when a particular nutrient is likely to become a limiting factor. On the other hand, on many soils, under many conditions, and with many crops, irrigation or fertilization or both may be desirable.

Though the water and nutrient requirements of annuals in their early seedling stage are small, they increase rapidly as the plants grow, and with many kinds are at their maximum at, or even before, midseason. It is important that during their period of rapid growth ample supplies of both water and nutrients are available. Even temporary deficiencies, especially of water supply, may prove harmful in causing a check in rate of growth from which the plant never fully recovers. This is especially important in the culture of plants such as lettuce, celery, carrots, radishes, and asparagus, whose leaves, petioles, roots, or stems are rated largely on the basis of tenderness and crispness and in which any check in growth is likely to be accompanied or followed by thickening of cell walls and lignification. With peas that are to be harvested in June and early July, May is a critical month for vegetative growth, flowering, pod setting, and seed development; with sweet corn that is to be harvested in August, July is critical; and with celery and cabbage that are to be harvested in September and October, August and early September are the critical periods for their vegetative development. Fertilizer applications for these crops, if made early in the season, should be of such kinds that their nutrients are becoming available in largest amounts at these critical times, or the timing of the application should be such that the same objective is attained in a different way. Thus an early-season application of manure while the land is being prepared for the crop may provide a late tomato or cabbage crop with its nitrogen when it most needs it, but it would be available too late in the season for an early spinach or early cabbage crop, and an application of a commercial, quickly available nitrate is called for. On the other hand, a preplanting application of such a fertilizer to a late maturing crop of celery in a nonretentive soil might be used up or leached away before the maximum plant demand develops, and a midseason side dressing would be more useful.

In general, broadcast applications are employed with grains, grasses, and other crops that completely cover the soil, while row or hill applications are employed with row and hill crops.

PEST CONTROL

In the chapter on "Plant Pests and the Injuries Caused by Them" mention was made of a number of groups or classes of insects and diseases that are parasitic on crop plants of one kind or another. Species belonging to all of these groups attack the annuals, but there is one major difference between the insect- and disease-control problem on annuals and the woody perennials. In the main the insects and diseases of the woody plants are comparable to "star boarders." They are regular patrons, permanent residents, systematic in their habits, and always to be counted on. Those attacking the annuals, on the other hand, are more in the nature of transients, sporadic in their visits; they come and go, something like the wandering tribes of primitive peoples, sometimes regularly, sometimes irregularly, and perhaps when least expected. The consequence is that while more or less regular or fixed spraying schedules or calendars can be devised and recommended for pest control in the nursery and orchard, such programs are hardly practicable in the garden. This does not mean that pest control is any less important or less difficult with the annuals. As a matter of fact, it is usually just as important and often more difficult, because it cannot be reduced to a set of rules. Instead the grower must learn to recognize the first evidence of insect presence or symptoms of disease injury and be prepared to employ at once suitable remedial or protective measures. For the fruit-grower each spray application is a kind of insurance, and the calendar or schedule tells him when the premiums are due. For the grower of annuals spraying is likewise a type of insurance but each premium is for an indefinite period, and he must depend on his own knowledge and observations to determine when the next one is due. Constant vigilance is the price he must pay for knowledge as to when the policy is about to lapse.

VARIETAL DIFFERENCES

At various places in this chapter and in a number of preceding chapters attention has been called to the influence of various environmental factors that affect rate of growth, size of plant, and yield of whatever part for which the plant is principally grown. Some reference has also been made to the influence of these same factors on season of maturity, on resistance to disease attack, and on quality of product, especially texture and flavor. Such influences are often very important and should always be utilized to the fullest extent practicable.

Equally important or even greater differences, however, are often associated with differences in variety, and the well-informed, discriminating grower will make use of them. The Redskin and Victor tomatoes will mature their fruits in forty to fifty days from setting in the field under the same conditions that require sixty to sixty-five days for Earliana and eighty-five to ninety days for the Ponderosa. No combination of cultural practices could be employed with the Ponderosa, or even the Earliana, to make them mature within the period required for the Redskin. Obviously Redskin and Victor are far better adapted to sections with relatively short and cool growing seasons. Similarly the Express type of cosmos that begins to flower some forty-five to fifty days after seeding is adapted to sections where the Sensation type that requires seventy to eighty days would be a complete failure. On the other hand, the Earliana and Ponderosa tomatoes and the Sensation types of cosmos possess characteristics of size and color that make them preferable to many in sections with longer and warmer growing seasons. Though lettuce varieties in general are cool-season crops, the Salamander and Black-Seeded Simpson varieties are tolerant of higher temperatures than are a number of the Imperial strains and consequently can be successfully grown in many sections where the Imperial fails.

Osage, Emerald Gem, Hearts of Gold, and Honey Rock cantaloupes require essentially the same conditions of soil, temperature, and light (though Emerald Gem has a slightly shorter growing season than the others) and may be grown with equal success in the same field or garden. The fruits of the Emerald Gem, if harvested when at the "just right" degree of maturity, held on ice overnight, and used the next day, have excellent flavor (though soft texture), but they are practically worthless later and are unsuitable for market; the fruits of the Osage are large and attractive, possess a good texture and an aroma surpassed by none, but they have a short storage season and are often disappointing in flavor; the fruits of the Hearts of Gold and Honey Rock varieties, on the other hand, may have a less pleasing aroma, but in keeping and storage quality and in color, texture, and flavor of flesh they are far superior to either Emerald Gem or Osage. Country Gentleman was once a leading sweet corn variety and in some sections is still being grown to a considerable extent, but elsewhere it has been largely supplanted by varieties of the Golden Bantam type that are of much higher quality. Heavenly Blue is not only larger in size and more attractive in every way than most of the older varieties of morning-glory (*Ipomoea hederacea*), but its flowers remain open most of the day while those of many others close by mid-forenoon.

Throughout the list of annuals, whether grown for food or for ornament, certain distinctive qualities for which they are especially valued can be obtained only in certain varieties, or it is only certain varieties that have these qualities developed to an especially marked degree. It is therefore as necessary for the grower to become as well acquainted with variety characteristics as it is for him to become expert in their culture.

STYLES, FADS, FANCIES, AND NOVELTIES

Every year witnesses the introduction of a number of new varieties of annuals. Indeed a large percentage of the seed firms introduce on the average at least one new variety each year, and some of them introduce several, and there is much competition between them for new kinds that give promise of proving widely successful. When first introduced, all these new kinds classify as *novelties*. Many prove little, if any, superior to kinds already in cultivation and soon disappear; a few find favor and gradually replace the older kinds. The novelty of today may become the standard of tomorrow. In view of the fact that seed stocks of novelties usually cost several times as much as those of standard kinds and that such a small percentage succeed, main reliance should be placed in well-tried and well-established kinds, though limited trial of the new kinds is always interesting and may provide timely information as to changes that should be made in the variety list for general culture. Usually more confidence can be placed in the claims made for new kinds that are being introduced by seed companies having long-established, well-earned reputations or, better still, that have been developed by plant breeders of recognized standing, than in novelties without such backing. Thus Russell lupins (*Lupinus*) or Spencer sweet peas (*Lathyrus odoratus*) or Jaegger lettuce strains are particularly promising for trial. More flower than vegetable novelties are introduced and, in turn, flower varieties generally remain in favor shorter periods than is true of vegetable varieties.

Accompanying, or incident to, changes in the lists of varieties of a number of annuals are certain trends that reflect either significant changes in demand or style or the appearance or disappearance of a fad. Thus in the course of three or four decades, leaf lettuce has largely given way to head lettuce, and within the head-lettuce group varieties of the New York or Imperial type have largely supplanted those of the Boston type. At one time, wax beans were more popular than the green podded type; the reverse is now true. Yellow sweet corn is now wanted almost to the exclusion of the white varieties. Odorless marigolds (*Tagetes erecta*) are taking the place of those with a strong aroma. All these are illustrations of what appear to be long-time trends. On the other hand, the introduction of varieties of cosmos of striking new color shades and of calendula (*Calendula officinalis*) with distinctive color shades and flower shape may represent little more than passing fads. Pansies (*Viola tricolor*) and phlox (*Phlox drummondi*) and bachelor's buttons (*Centaurea cyanus*) are not grown nearly as much as formerly; they have gone out of style — perhaps only temporarily, perhaps permanently.

PROBLEMS

1. What evidence can you present to indicate that for certain crops a long cool season will not be the equivalent of a shorter warm season?

2. Does a four-week start in a greenhouse or hotbed at an average temperature of 60° F. and then transplanting to the garden, enable a plant to mature four weeks earlier than it would if seeded in the garden at the end of the four-week period, after which the temperature averages about 60° F.? Explain why.

3. Would you consider it better practice to sow seeds in the field or garden just before or just after a rain? Why? Would the answer be the same for transplanting to the field or garden from the hotbed?

4. Wherein lies the difference, if any, between a hardy and a hardened plant?

5. Would the hardening of tomato plants grown in plant bands and intended for transplanting to the garden be more or less necessary than it would be for tomato plants grown rather thickly in seed beds and transplanted directly to the garden without a ball of earth? Why?

6. Why do we generally consider it necessary to transplant evergreen trees and shrubs with a ball of earth when we don't consider such a precaution necessary with ordinary deciduous trees and shrubs? Would young vegetable plants started in hotbeds in the spring and intended for transplanting out of doors classify with the evergreen or with deciduous trees in this matter of transplanting? Why?

CHAPTER XX

THE CULTURE OF BIENNIALS, HERBACEOUS PERENNIALS, AND BULBOUS PLANTS

AS EXPLAINED in Chapter II on the "Classification of Plants" and as the name itself implies, an annual is a plant that completes its life cycle from seed to seed within a year. Biennials characteristically live for two years and perennials for three or more years. There are, however, many kinds that do not readily fit into any one of these groups or that, though classifying in one group or another, present certain exceptions from the standpoint of culture. Among the more important of these, horticulturally, are the plurannuals.

PLURANNUALS

Many so-called annuals with an "indeterminate" type of growth are annuals only when grown under conditions which limit their life span to a single season. Thus, most varieties of the tomato will produce flowers within ten or twelve weeks of the time seed is sown and ripen fruit and mature seed a few weeks later. An entire life cycle is thus completed within four or five months, but the plant itself does not die unless destroyed by frost, disease, insect attack, or exhaustion from overbearing. This is well illustrated by the tomato plants shown in Figure 178. The plurannual continues to make more vegetative growth, produce more flowers, fruits, and seeds and may do so more or less indefinitely if environmental conditions remain favorable, though it is seldom found practicable to encourage such long life in the tropics or in the greenhouse. Larger returns are obtained from expenditure of time and labor by growing them as annuals, though perhaps as long-season (for example six to ten months) rather than as short-season (three to six months) annuals. Thus, greenhouse-grown tomatoes are usually trained to single stems and allowed to grow until they become too tall for tying to the wires or stakes, artificial pollination, and harvesting.

Among flowering annuals the petunia (*Petunia hybrida*), the China aster (*Callistephus chinensis*), the verbena (*Verbena hybrida*), the ageratum (*Ageratum houstonianum*), and many others behave much as does the tomato, and as a rule the gardener wants them to continue to grow and blossom until frost or other unfavorable weather conditions make further growth impossible. Many of the herbaceous ornamentals commonly grown as house plants or in the greenhouse have the same general growth characteristics and may be kept for many years. When, because of size or shape or lack of symmetry or loss of older leaves or for any other reason, they become unwieldy or unattractive, they may be cut back to make them rebranch and form new tops, or they may be destroyed after cuttings have been taken from them for renewal purposes. The geranium (*Pelargonium domesticum*), pelargonium (*Pelargonium zonale*), coleus (*Coleus verschaffeltii*), and many of the begonias are good examples of this group of plants. Their principal point of difference from the plurannuals of the vegetable garden is that they are commonly propagated by means of cuttings rather than by seeds.

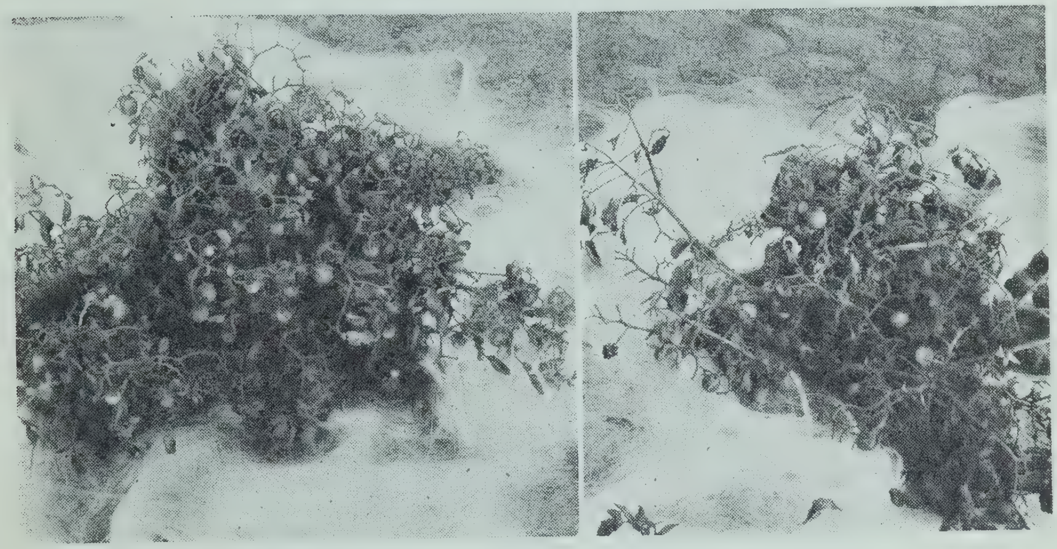


Fig. 178. Plants of the Farthest-North tomato, a very dwarf, extremely productive, extremely early maturing variety. Both of these plants were seeded at the same time and grown side by side under the same conditions and in the same way, except that the one on the left had its fruit clusters thinned to prevent overbearing. That plant is still vigorous and productive, while the other has literally borne itself to death.

During the early part of the growing season, plurannuals have essentially the same cultural requirements as the annuals. From then on, however, they call for somewhat different care. While the typical annual is producing its *crop* of flowers, fruits, and seeds, each within fairly restricted time limits and accompanied by very little if any new vegetative growth, the plurannual characteristically is producing *some* flowers, fruits, and seeds and at the same time is making *some* additional vegetative growth so that there will be a prolonged or continued production of flowers, fruits, and seeds. Expressed in another way, the typical annual has a distinct vegetative phase followed by a distinct reproductive phase with very little overlapping; the plurannual has a vegetative phase followed by a period when vegetation and reproduction proceed simultaneously. During their strictly vegetative periods both types require an abundance of moisture and nutrients. As the true annuals become reproductive, they not only require less water and nutrients, especially nitrogen, but they actually do better with less; as the plurannuals enter the stage where reproduction and vegetation proceed together, they require distinctly more moisture and nutrients, especially nitrogen, than the annuals, perhaps more than they themselves required earlier in the season. More attention needs to be given to weeds, more to late-season insect and disease control, while temperature, light intensity and length of day continue to exert a relatively important influence on them. This does not necessarily mean that they are more difficult to grow; they are on the average, however, longer-season crops, and they require care over a longer period.

BIENNIALS

Most biennial vegetables, such as cabbage, carrots, beets, and celery, occupy the land for only a single growing season. It is their vegetative organs such as roots, crowns, stems, or petioles for which they are raised, and these structures attain their maximum development the first year. On the other hand, most biennials grown as ornamentals, such as the Canterbury bell (*Campanula medium*), foxglove (*Digitalis purpurea*), and hollyhock (*Althaea roseum*), occupy the ground for two years because it is their flowers for which they are raised, and these do not appear until the second season. If the biennial vegetables are grown for their seed, they too must be left for two years.

Cultural methods suitable for biennials their first season may resemble those suitable for typical annuals or those suitable for plurannuals, or it may be something intermediate between the two, depending on the kind that is being grown, on conditions and on objectives. Thus, in the South early cabbage and carrots are raised to place on the market in late winter or early spring, just as are lettuce, spinach, and string beans; in the North these same crops are intended for market in late spring and early summer. With this objective in view, they are seeded in, or transplanted to, the field at such times as weather conditions permit, and such intensive cultural methods are employed as will enable them to grow rapidly until a certain amount or degree of vegetative growth has been made. Somewhat less intensive culture is then afforded while they are developing their storage tissues and, like spinach or string beans, they are harvested and placed on the market when their storage tissues are well stocked with foods but are still tender, crisp, and succulent. In neither instance is the life cycle of the plant completed, though perhaps in the case of the string beans it more nearly approaches completion. On the other hand, late celery, parsnips, and rutabagas are left to grow as long as weather conditions permit and, like such plurannuals as tomatoes, peppers, or petunias, are cultivated and otherwise cared for in such a way that maximum vegetative growth will be made, consistent with a considerable accumulation of foods for later reproduction. The same easing off in intensity of cultivation that results in heavy late-season fruiting in the tomato and late-season flowering in the petunia, results in late-season storage — for late fall harvest or for next season's flowering — in the late celery, parsnip, and rutabaga.

Second-season culture of the biennial ornamentals and of the biennial vegetables that are grown for their seed crops is comparatively simple. If climatic conditions are such that they can be left in the ground all winter, they are ready to make a rapid, vigorous, vegetative growth in the spring. This is largely at the expense of the food supplies accumulated by them the preceding season, and this vegetative growth practically assures the production of flowers, fruits, and seeds. There is seldom any need of fertilizer application the second year, and though some cultivation to destroy weeds may be necessary, the strong rapid growth that the plants make gives them a distinct advantage over annual weeds that must start from seed and compete with them. Cultivation should be shallow so as to disturb their roots as little as possible. Irrigation and spraying early in the season may be necessary with certain kinds, but during the period while the fruit is developing and the seed is maturing, little attention of any kind is likely to be required. Reserve foods stored anywhere within the plant and products of current photosynthesis within the leaves are being translocated to the flowers, fruits, and finally the seeds, accompanied by lignification within the stems, thus making them progressively less susceptible to insect and disease attack.

HERBACEOUS PERENNIALS

In humid tropical or semitropical regions and in northern greenhouses, the cultural requirements of plurannuals and herbaceous perennials are very much alike. Nevertheless they form fairly distinct cultural groups wherever winter cold or summer drought necessitates an alternation of growing and resting periods. Typically, the herbaceous perennial, like the biennial in its second season, makes a strong, vigorous, vegetative growth in spring or early summer at the expense of food materials stored in crowns, rhizomes, roots, or other below-ground organs, and its full stature is attained fairly early. Though many species blossom in midseason or even later, by far the greatest number blossom early, and in many cases fruits and seeds mature by midseason. Consequently, it is herbaceous perennials that furnish the earliest spring vegetables (for example, asparagus, rhubarb, and endive) and garden flowers (for example, phlox (*Phlox subulata*), columbine (*Aquilegia vulgaris*), peony (*Paeonia albiflora*), iris (*Iris*), Shasta daisy (*Chrysanthemum frutescens*), larkspur (*Delphinium ajacis*), and oriental poppy (*Papaver orientale*).

Like the biennials which make their second season's growth quickly and at the expense of stored foods, the herbaceous perennials demand comparatively little in the way of early-season care. Simply provide them with enough shallow cultivation to control weeds, and they will be able pretty well to "look out" for themselves. On the other hand, the latter half of the growing season is a critical period for them, just as is the latter part of their first year for biennials. It is then that they recuperate from flowering and fruiting, that their roots are absorbing the nutrients and their leaves are manufacturing the carbohydrates and other food materials with which their storage organs are being stocked and of which they must have an abundance if they are to make a satisfactory growth the following year. Consequently, that is the time they must be provided with an abundance of water, an ample supply of available nutrients, and be protected from the depredations of insects, the weakening effects of disease and competition with weeds. In the case of such crops as rhubarb and asparagus, harvesting should not be continued too late so as unduly to exhaust the store of reserve foods in the crowns and not provide for ample new foliage and ample time for recuperation and restocking with foods in summer and fall. In the case of perennials that flower late in the season, such as the hardy outdoor chrysanthemums, it is always good practice in cutting the flowers to cut high enough so as to leave considerable foliage. It may be a good plan with some kinds to do some disbudding so as not to exhaust completely all food reserves. With species like the oriental poppy (*Papaver orientale*) whose leaves die down a short time after flowering, the short period between flowering and loss of leaves is extremely important and nutrient and moisture supply and other environmental conditions should be kept at as near their optimum as is possible.

BULBOUS PLANTS

As explained in Chapter II on the "Classification of Plants," the term *bulb* is used in a narrow sense to apply to a certain type of fleshy bud and in a broader sense to include many more or less similar, or at least comparable, vegetative structures. Thus, the common Irish potato which produces tubers instead of bulbs and the sweet potato and yam (*Dioscorea batatas*) which produce tuberous roots, are commonly spoken of as *bulbous plants*.

In a sense, the term *herbaceous perennials* might be used to include bulbous plants of all kinds, for, like typical herbaceous perennials such as asparagus and larkspur (*Delphinium ajacis*), though their tops die down at the end of the growing season, they may live for many years without the necessity of being renewed from seed. Indeed, many kinds, such as the Iris, are as often classified with the one group as with the other. In general, however, if the vegetative rooting structure is more or less fleshy and compact, and if it grows so that it *separates* naturally or readily from the parent plant, instead of requiring artificial division of the parent plant, we classify it as a bulbous structure and the plant as a bulbous plant; otherwise it is more likely to be classified as an herbaceous perennial.

Typically the early-season growth of bulbous plants is comparable to that of the herbaceous perennials just described, and for the same reasons. The bulbs, tubers, or other structures are themselves packed with reserve foods that are used for the development of stems, leaves, and flowers upon the appearance of favorable conditions. Development of both vegetative and reproductive organs usually proceeds rapidly, in some species being completed within a few weeks. Fruit and seed (or bulblet) production follows in quick succession, and then the plant enters a long resting stage. The very short interval between blossoming and the dying down of the above-ground portion of the plant is the critical period in the culture of most bulbous plants, for it is then that they must absorb the bulk of their nutrients, manufacture their season's supply of carbohydrates, recover from the drain of flower and seed production, produce vegetative reproductive organs in the shape of bulblets, cormels, etc. — in brief, prepare for the following season's growth. It is, therefore, obvious that the bulb-grower must do everything possible to provide ideal growing conditions during this critical period. This means far more than is implied in the phrase *drying off*, which many who grow bulbous plants apply to that period.

In general, a limited soil nutrient supply, rather dry soil, low atmospheric humidity, and high temperature contribute to rapid drying off and quick ripening of the bulb, but they all tend to limit nutrient absorption, food manufacture and storage. On the other hand, an abundant nutrient supply, a moist soil, rather cool weather, and a high atmospheric humidity prolong the food-manufacturing and storage period and tend to the production of larger and better bulbs or other comparable vegetative organs. Long photoperiods, that is, long days and short nights, such as are found in early summer in the more northern latitudes, similarly contribute to the rapid accumulation of the products of photosynthesis. It is not just accident that has led to the development of the major bulb-growing industries in Belgium, Holland, Long Island, the Puget Sound region, and western and northern Michigan.

Incidentally, the statements made in the preceding paragraph explain why most bulbs used for greenhouse forcing are of little value for forcing a second time or for outdoor planting, especially if much of the foliage is removed when cutting the blossoms. This point is well brought out in Figure 179. They also explain why many bulbs "run out" under average conditions or with just average care. With better care during the after-blossoming, ripening, or drying-off period many could be used again and again.

Following ripening or drying off, bulbs are usually dug, spread out to dry for a short time, either in the field or under cover depending on conditions, and then they are stored in a cool dry place. Thorough drying is necessary to prevent decay, and storage at a moderately low temperature is necessary to keep the bulbs from sprouting.

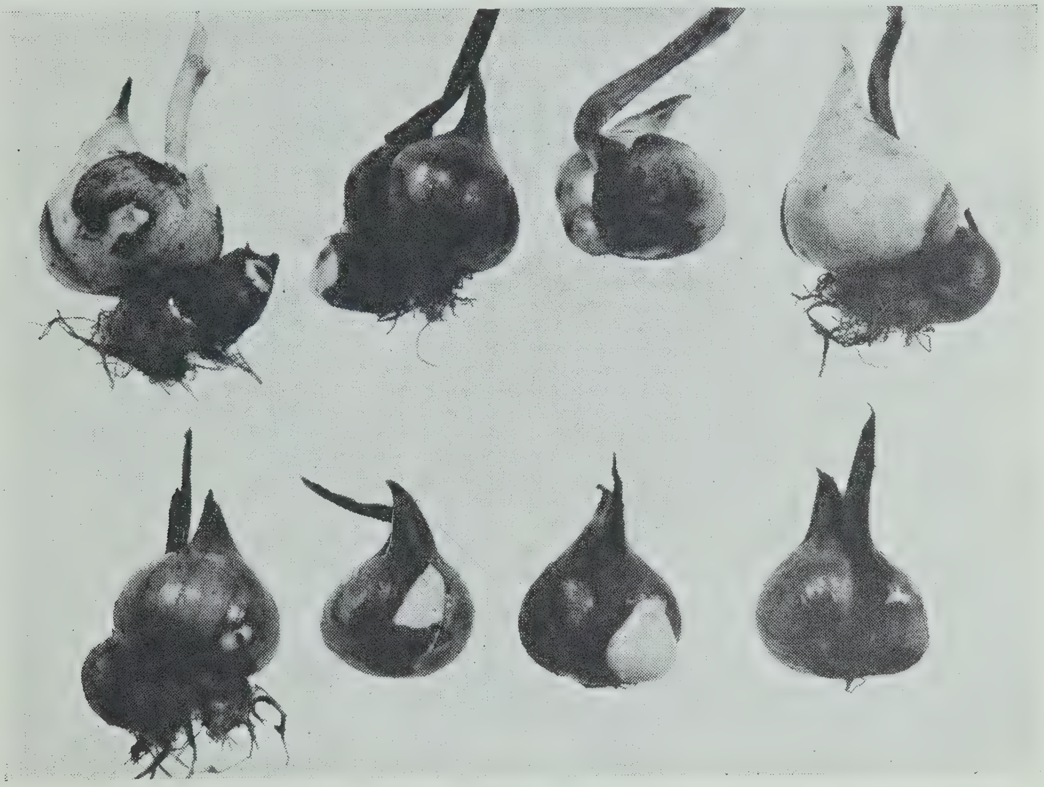


FIG. 179. These eight bulbs, from a lot that was dug right after flowering, were selected for uniformity of size. The ones in the upper row were heeled in for ripening with most of their leaves attached; the ones in the lower row were ripened after low cutting of the blossoms that removed most of their leaves. Note the difference in size.

Under ordinary field or garden conditions, bulbs may be set in the fall, provided the ground does not freeze too hard and too deep, or very early in the spring. Fall planting is generally preferred if the bulbs are hardy or if the winters are not too severe. They generally become well rooted in fall and winter and start earlier in the spring. For greenhouse forcing they are usually planted in flats, pots, or bulb pans in early fall and then held in storage in darkness at relatively low temperatures until time to start forcing at a higher temperature and in the light so as to reach the opening-bud or full-bloom stage at some desired time.

Bulbels, cormels, and similar structures are handled in essentially the same way as that just explained for bulbs. Because of their smaller size they are usually planted closer together. It takes from one to six or seven years, depending on the species and on how they are grown, for a bulbel or cormel to attain flowering size.

BULBOUS PLANTS RAISED AS ANNUALS

A few bulbous plants, such as the onion, are grown from seed and raised as annuals. Others, for example, multiplier or top onions, are started from small bulblets or bulbels and then grown as annuals. The Irish potato is grown from tuber cuttings; the sweet potato is grown from sprouts produced by its tuberous roots; both are cultured as annuals. With all of these plants early-season culture is more like that afforded annual plants than typical bulbous plants, for they do not start the season with a large supply of stored foods. Their midseason and late-season culture may be more like that of the annual, the typical bulb, or the herbaceous perennial, depending on kind and conditions. Thus, the onion undergoes a considerable degree of field ripening before being dug; the sweet potato undergoes no such ripening in the field but is cured following harvest; the Irish potato occupies a more or less intermediate position.

PROBLEMS

1. What kind of cultural treatment would you suggest for making a plurannual out of an ordinary annual? An annual out of a plurannual? Give reasons for the difference.
2. In what respects does the second-season culture of a biennial resemble that of an herbaceous perennial, and in what respects does it differ? Explain why.
3. From the standpoint of their most successful culture and attaining maximum development, is the critical period or season the same or different for annuals than for bulbous crops? Explain.
4. What is the difference, if any, between a tuber and a tuberous root?
5. Are the reasons for planting bulbs in the fall the same as those for planting trees and shrubs in the fall, or are they different? Explain fully.
6. Seeds of many annuals are often started in the greenhouse, hotbed, or cold frame, to be later pricked off and finally transplanted to the field. This practice is far less common with biennials. How do you account for this difference?

CHAPTER XXI

THE CULTURE OF WOODY PERENNIALS

WOODY perennials present fully as much diversity in form, structure, and manner of growth as do annuals and an even greater range in size. As with annuals, some are grown for their fruits, some for their seeds, some for their leaves (for example, the tea plant), some for their stems, some as drug plants, and many are cultivated as ornamentals. Others are raised for their wood, bark, sap, or latex. Perhaps larger percentages are raised for their fruits and seeds and smaller percentages for leaves or buds, though the clove of commerce (*Eugenia aromatica*) is a dried flower bud, and the terminal "heart" of the cabbage palmetto (*Sabal palmetto*) is considered one of the choicest salads. From the standpoint of culture, the small grains and pasture crops have their counterpart in the forest where tree seedlings crowd each other, and only a small percentage eventually survive in the struggle for existence; row crops have their counterpart in the windbreak and hedge, hill crops in the vineyard and orchard.

LIFE HISTORY OF WOODY PERENNIALS

Basically the seasonal life history of the woody perennial is essentially the same as that of the herbaceous perennial, except that its top does not die down at the end of the growing season, to be replaced with a new one the following year. In some species, for example, the black raspberry (*Rubus occidentalis*) the top lives for only two growing seasons; in many shrubs it survives for only a few years, being shaded and starved out by younger, more vigorous wood; in most trees and vines it characteristically lives as long as the crown and roots, though if destroyed by insects, disease, or accident it may be replaced by sprouts or suckers. The age of the top of the mock orange (*Philadelphus*) shown in Figure 180 was probably less than ten years when the photograph was taken, though its crown and older roots were at least half a century old. The clumps of trees springing from a common point, so characteristic of certain species, such as the paper birch (*Betula alba*) and some of the alders (*Alnus*), are evidence of sprouting from roots or crowns perhaps several times or even many times as old as the tops. Individual plants of the woody perennials, consequently, may have tops and roots almost as different from each other in age as are those that characterize herbaceous perennials.

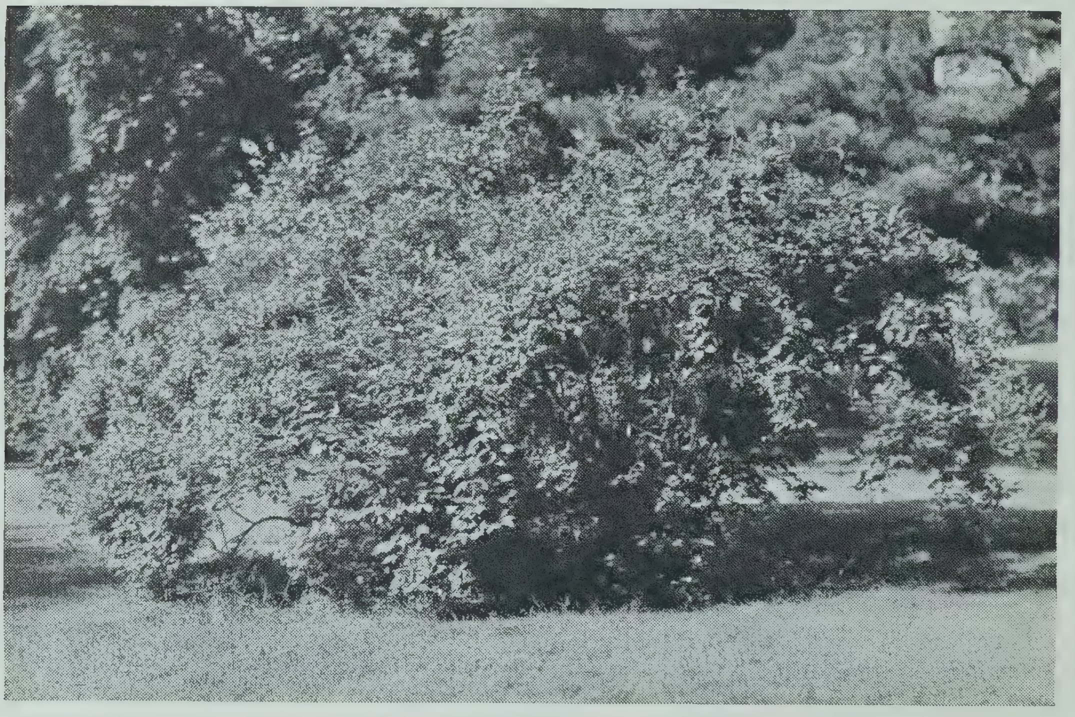


FIG. 180. A mock-orange (*Philadelphus*) bush known to be over fifty years old, though none of its stems are more than ten years of age.

Whether the roots and tops of woody perennials are of the same or of different ages, however, their stems and branches function as food-storage organs. This means that, over and above direct uses that may be made of the stems themselves, they assume an importance not attached to those of herbaceous plants. They must be protected from insect, fungous, bacterial, rodent, and mechanical injury; they must be properly trained and pruned; due attention must be given to cultural and other practices that will guard against injury from extremes of temperature. These matters cannot be entirely overlooked or ignored in the culture of many annuals, biennials, or herbaceous perennials, but they assume considerable added importance in woody perennials.

GROWTH PERIODICITY AND ITS IMPLICATIONS

As already explained, biennials, bulbous and tuberous-rooted plants, and a large percentage of herbaceous perennials are characterized by a distinct periodicity of growth. That is, they grow rapidly for a while, then enter a dormant or resting period, which in due time is followed by another period of active growth. Even some annuals, such as winter wheat and many other species and varieties, both as they grow naturally and as they are cultivated, make a more or less rapid vegetative growth in the fall following germination and while conditions are favorable, then suspend growth during the winter, and resume growth and complete their life history in the following spring and summer. In the sense that in a great many species there is a distinct alternation between vegetation and flower, fruit, and seed production, a large percentage of herbaceous plants shows growth periodicity. Periodicity, however, is more marked and more widely found in woody than in herbaceous plants. In temperate regions, winter cold enforces a period of inactivity on all woody plants. Many deciduous species, such as the high-bush blueberry (*Vaccinium corymbosum*), rather characteristically make two flushes of growth in the course of a single growing season, no matter what the nature of the environment; others sometimes make two or more flushes in response to environmental conditions.

In tropical regions drought or extreme heat may similarly result in periods of inactivity or very slow growth. Even where environment is favorable for continuous growth, many species fail to grow continuously or evenly. They grow vigorously for a while; then growth slows down or stops; then it may be resumed. There may be several alternating periods of growth and rest in the course of a year, and they may come at regular or irregular intervals, or one side or part of a plant may remain in a resting stage while the rest makes a new flush of growth. There seems to be little relation between these flushes of growth and environmental conditions, the beginning, duration, and ending of the resting periods apparently being due primarily to internal conditions. The mango (*Mangifera indica*) and the croton (*Codiaeum variegatum*) are examples of tropical fruit and ornamental plants showing marked periodicity in vegetative growth. Most species showing periodicity in their natural habitat behave similarly when grown in the greenhouse.

The flush of growth that woody plants make following a period of rest is usually completed quickly and is at the expense of stored food materials, which in the case of deciduous species were synthesized the preceding season, or synthesized before and during the period of rest in the case of evergreen species. Obviously a prerequisite to a strong flush is an abundance of stored foods, and this necessitates the late retention of leaves during the growing season in deciduous species and during both growing and resting seasons in evergreen species. Premature defoliation from drought, starvation, spray injury, insect and disease attack, or other agencies limits food manufacture and storage and makes impossible normal growth the following season. The significance of this factor in the culture of woody plants is not fully appreciated by many growers. To them premature defoliation means simply a longer period of dormancy. They don't stop to think that a dormant (leafless) plant isn't a food-manufacturing plant, while one with green leaves is continuing to manufacture food. In a northern state a cherry tree that is defoliated by the leaf-spot disease in early August — not at all infrequent in many commercial orchards — has its food-manufacturing possibilities for the year reduced by 50 per cent, as compared with one that retains its foliage until it abscises normally. This is important not only from the standpoint of the amount of the following season's growth but from that of proper ripening and hardening of wood to withstand low winter temperature. In a tropic or subtropic region partial defoliation of a mango, palm, orange, or avocado tree or a croton plant as a result of frost or lack of care has a similar weakening influence, often more pronounced than in the deciduous plant because production of a new lot of their thick, leathery leaves requires a larger quantity of stored foods. This, incidentally, is one of the reasons why frosts and freezes are relatively more serious with subtropical evergreen than with deciduous plants; in deciduous species it is usually flowers only that are destroyed, with evergreen species flowers, fruits, and leaves are often destroyed, and full recovery may take a much longer time.

Though periodicity of growth is a normal characteristic of many kinds of woody plants, a method or process of adjustment to certain environmental conditions, extreme or even moderate variations from normal periodicity often occasion serious problems for the grower. Especially along the southern borders of the range of many species winter cold is often insufficient thoroughly to break their rest period. The result is delayed starting in the spring and irregular foliation, blossoming, and fruit setting, followed by correspondingly uneven ripening — in brief, a lack of synchronization between their different branches. The delicacy of balance or adjustment within the plant to environmental influences affecting periodicity is illustrated by the fact that the difference between mean temperature on the two sides of a building may be sufficient for a tree to behave normally where grown on the north side in the shade while it shows very erratic spurts or flushes of growth on the south side in the sun. It is this factor principally that sets the southern limits to the practicable culture of the peach, apple, and a number of other fruits. A number of forest trees, such as the southern cypress (*Taxodium distichum*), and a number of ornamentals show similar irregularities in periodicity, but with them the problem is less serious. At the other extreme along the northern borders of the range of some of these same and other species premature breaking of the rest period by certain spraying treatments that are desirable from the standpoint of pest control often predisposes the plant to injuries resulting from vegetating and blossoming at an earlier date than it otherwise would. Fall applications of oil sprays to certain fruits often prove dangerous on this account. In the forcing of woody perennials in the greenhouse fairly complete control of periodicity is possible through the control of temperature at different stages of growth, coupled with the use of such agencies as etherization or exposure to other chemicals for the purpose of breaking the rest period.

FLOWER-BUD FORMATION AND ITS IMPLICATIONS

There is nothing fundamentally different about the process of flower-bud differentiation and development in woody perennials than in herbaceous perennials or annuals. In all plants it depends on the development of vegetation to a certain point or stage — at least a certain minimum size must have been attained. This point of development apparently is associated with certain internal nutritive conditions; in many plants it is in some manner greatly influenced by length of daylight. This last factor is a feature of environment, and the other factors are greatly influenced by this same and other features of environment. The fact, however, that the literature on plant culture contains relatively little on flower-bud formation in the annuals and herbaceous perennials, and relatively much in the case of the woody perennials indicates that the process presents certain practical problems in the one group that are not met with in the other. Growers of the woody perennials are flower-bud conscious while growers of nonwoody plants are not. The reason for this difference in attitude or consciousness lies in the fact that seldom is flower-bud differentiation itself a limiting factor to productivity in herbaceous plants, while it often is in woody perennials. When the time arrives for flower buds to be differentiated and developed in herbaceous plants, they differentiate and develop, automatically it seems; indeed, there is little the plant-grower can do to prevent it. Size of plant, and to some extent environment, limit the number that can be formed, but in the main large numbers are produced on large plants, and the problem of securing a large production of flower buds, flowers, fruits, and seeds is principally a problem of first obtaining a large amount of vegetative growth. This is not true with woody plants, at least to anything like the same degree. Great numbers of flower buds and flowers obviously cannot be borne by small plants, and securing a reasonably large amount of vegetative growth is just as important with woody as with herbaceous plants. However, flower-bud formation does not follow automatically in them; very large, vigorous plants may remain flowerless for many years, and then they may bear very lightly.

As explained in Chapter XI on "Growth and Fruitfulness," flower-bud differentiation takes place in many different species and varieties only during certain rather limited periods, those periods apparently often being determined by length of day. These periods vary with the species, and there is hardly a time during the growing season when differentiation is not taking place in one kind or another. If flower buds are to be differentiated in large numbers, there must be a relatively high carbohydrate-nitrogen relationship during those critical periods. This ratio is influenced not only by nitrate intake by the roots and carbohydrate manufacture by the leaves, but by the current rate of nitrate and carbohydrate utilization. This in turn is influenced by water supply, amount and rate of new vegetative growth, and the amount of growth being made by developing flowers, fruits, and seeds.

During their first few years following planting most woody perennials do not flower and set fruit and seed, mainly because they utilize a large proportion of their carbohydrates for vegetative growth as rapidly as they are being manufactured. This is desirable from the standpoint of obtaining as large a plant as possible within a short time. Vegetative growth can be promoted and flowering delayed by the use of nitrogenous fertilizers, a desirable practice where the plants show a tendency to come into bearing before they have acquired what the grower regards as sufficient size for a producing plant. Frequently woody perennials grow too vigorously and remain vegetative after they have attained a size and age when the grower wants them to form flower buds, flowers, fruits, and seeds. This is a particularly serious problem in orchards on fertile, well-watered soils. It can be dealt with by such practices as placing the orchard under a sod method of soil management, withholding fertilizers, reducing pruning to a minimum, and perhaps ringing or notching the trunk or main branches.

In open-grown (that is, not crowded) specimens of plants such as the elms, maples, golden bell (*Forsythia suspensa fortunei*), rhododendrons, and magnolias, which flower very early in the spring and mature their fruits and seeds only a few weeks later, there is ample opportunity for an accumulation of carbohydrates before their period of flower-bud differentiation, even though it comes in early summer. Consequently they seldom fail to flower freely, unless they should be deprived of their leaves during this critical period by caterpillars, drought, or fungous injury. In crowded stands, on the other hand, there may be insufficient food manufacture for flower-bud differentiation.

In such kinds as the apple, pear, and mountain ash (*Sorbus americana*) in which flower-bud formation characteristically occurs in July and early August, and where there have been heavy flowering and fruit setting, the drain of the latter processes on stored food reserves and of the developing fruits on foods being currently manufactured is often so great that the limited supplies are inadequate for flower-bud differentiation; few or none will be formed and the tree has an "off" year. Apparently the same condition often characterizes the orange, lemon, and grapefruit in late winter and early spring when their flower buds are being differentiated. In the culture of such forms the grower often has a rather difficult problem in attempting to establish and maintain a proper balance between their vegetative and reproductive activities Nevertheless, through the use of fertilizers, pruning, disbudding, and flower or very early fruit thinning he can limit blossoming and prevent overbearing one season and thus reduce the likelihood of insufficient food reserves for flower-bud formation. To apply these measures effectively, however, he must know when flower-bud initiation normally occurs in the species or variety in question and so time these practices that their influence is registered at the critical period. In spite of such measures complete regularity of bearing has seldom been obtained with certain varieties very prone to alternate bearing.

There are many species and varieties, such as the peach, cherry, and Tartarian bush honeysuckle (*Lonicera tartarica*) in which flower buds seldom fail to form in sufficient numbers, even though the flowers open early and the fruits ripen in midseason or later. With them the principal concern of the grower is to limit flower-bud formation, flowering, fruit and seed production so that reproduction does not unduly limit vegetative growth. This is an annual objective or procedure in the culture of these plants. With species such as the apple and pear that tend to bear biennially it is necessary only every other year.

MATURITY OF WOOD

When an annual plant matures its seed crop, its vegetative organs die, and the question of its maturing them in preparation for winter or a period of intense heat or drought never arises. In the case of biennials, bulbous and tuberous-rooted plants, and herbaceous perennials, the tops similarly die down at the end of their growing season, though their crowns, roots, and other below-ground organs remain alive and are subject to the influence of environmental factors, some of which may be unfavorable. They are, however, protected by the soil from the extremes to which the tops of woody perennials are regularly subjected. Low atmospheric humidity and low winter temperature are the two most harmful features of environment which the tops must endure, though sometimes intense heat, high atmospheric humidity, dense shade, or some other condition may prove almost as injurious.

Newly formed woody tissues are especially sensitive to all extremes of environment, and the top as a whole is relatively susceptible to injury during and immediately after periods of active growth. As the tissues become older — except for the cambium and relatively limited scattered bits of meristem in buds and other growing points — water content is reduced, cell walls become thicker, and lignification occurs. Even the cells of the cambium and meristem that do not undergo lignification increase in dry matter and undergo changes in composition that enable them to endure lower temperatures and to resist a certain degree of desiccation. These changes together effect what we commonly call a *ripening* or maturing of the wood — the term being used here in a broad sense to include wood, cambium, and bark. If this ripening or maturing process goes far enough, the tissues in question are able to endure great extremes of cold and drought.

Much can be done by the grower to delay or accelerate ripening of the wood. Failure to give this matter the attention it deserves has been responsible for many serious plant losses. Injudicious use of fertilizers, especially those high in available nitrogen, delays maturity. Reduction in the water content of the soil during the latter part of the growing season, sometimes accomplished through withholding irrigation water, sometimes through the use of cover crops, is one of the most effective ways of promoting early maturity. Of almost equal importance is the protection of the leaves from insect and disease injury so that premature defoliation does not occur, thus cutting off the supply of foods that are utilized by the plant in its lignification and other ripening processes. Overbearing has much the same effect as premature defoliation in retarding ripening of the wood through utilizing for fruit and seed production food materials needed for hardening. This may be prevented by proper pruning and thinning earlier in the season.

Seldom does the entire top of a plant ripen evenly or all of its parts acquire a uniform degree of maturity. Its crown, crotches, and the tips of its branches, especially its longer and younger shoots, are usually more susceptible to injury from low temperature than other parts. Killing back of the ends of raspberry and blackberry canes or of shoots of the grape, butterfly bush (*Buddleia davidi*), or Anthony Waterer spiraea is of common occurrence and, unless very severe, of little consequence. The dead and winter-injured portions are pruned away the following spring with little reduction in yield of blossoms or fruit and perhaps with some improvement in size and quality.

Often plants may be grown far north of where they would kill back almost to the ground without any protection, by bending their tops to the ground in the fall and covering them with straw or other mulching material. If upright in growth habit, they may be jacketed with a protective coat of some kind. Thus varieties of grapes and raspberries with comparatively tender canes may be grown successfully in the Dakotas by so training them that they may be laid on the ground and covered during the winter. Rose bushes that have first been pruned back, then had their branches tied together, and finally have been packed and surrounded by straw that is held in place with a burlap cover are a common winter sight in many northern gardens. The same methods are used to grow the youngberry (*Rubus trivialis vitifolius*) in southern Ohio, dwarf kumquats (*Fortunella japonica*), and calamondins (*Citrus mitis*) in southern Georgia, crotons in central Florida, and some varieties of figs in Rhode Island. Winter injury to the crown may be prevented by mounding soil up around the trunk to a height of several inches or even a foot. This is a regular procedure in citrus groves along the northern borders of their practicable cultural range, being especially important with young trees. Localized winterkilling of tender crotch tissues is best avoided by so training the trees that the formation of sharp-angled crotches is prevented, the tissues of such crotches being slower to acquire maturity than those more fully exposed to the sun.

PROBLEMS

1. From the standpoint of its influence on winter hardiness would a relatively high nitrate content in the soil during late summer and fall be more or less desirable with woody perennials than with herbaceous perennials? Why?

2. Would you expect plants that show extreme periodicity in their vegetative growth (that is, that have several flushes in a single growing season) to be more or less susceptible to injury from winter cold than those showing less extreme periodicity? Why?

3. **From the standpoint of the plant's welfare does blossom or fruit thinning serve any purpose in the case of annuals that it does not serve in the case of herbaceous perennials? What purpose in the case of woody perennials that it does not in the case of herbaceous perennials? Explain.**

SOME GENERAL QUESTIONS AND PROBLEMS

1. What conditions in the modern home govern the selection of plants for growing as house plants? Name five plants that are commonly grown as house plants that meet these conditions and five whose house culture is often attempted that fail to meet them.

2. To what extent do the same and to what extent do different features of the climate set the northern limits to the culture of (*a*) watermelons, (*b*) pears, (*c*) grapes, and (*d*) potatoes? Explain fully.

3. Peaches, grapes, and watermelons are raised not at all or only in very limited quantities and with rather poor results in a number of northern sections. Are the specific reasons for this lack of success the same with all these fruits or are they different? Explain fully.

4. Commercial production of many horticultural crops is localized to a rather marked degree: for example, grapes and peaches in southwestern Michigan, head lettuce in the Imperial Valley of California, oranges in central Florida, cantaloupes in parts of Colorado, mushrooms in eastern Pennsylvania, watermelons in Georgia. How do you account for this? It is gradually becoming much more localized. How do you account for this?

5. Sweet corn and cantaloupes are both frost-tender crops. Would you recommend essentially the same temperature conditions for the two in order to obtain maximum yields? In order to obtain highest quality? Why? Explain fully.

6. Enumerate at least four of the most important factors that determine how fast the plant takes up water from the soil and tell which are most and which least under the grower's control and by what means. Apply the same problem to nutrient materials.

7. Some advise deep plowing and deep fitting of land before planting to vegetables and then deep cultivation after planting; some advise deep plowing and fitting, followed later by shallow cultivation after planting; others advise shallow plowing and fitting, followed by deep cultivation after planting; still others advise shallow plowing and fitting followed by shallow cultivation after planting. Which is the best advice and why? Which is the poorest advice and why?

8. For maximum yields of crops grown for leaves or stems, would you advise or prefer a water and nutrient supply above or below the mean or average? Why? Present evidence. Would the recommendation be the same for maximum quality?

9. For maximum yields of crops grown for their fruits or seeds, would you advise or prefer a water or nutrient supply above or below the mean or average? Why? Present evidence. Would the recommendation be the same for maximum quality?

10. Would you expect frequency and thoroughness of cultivation to have greatest influence on quality of crop, size of crop, or earliness of maturity? Explain why. How about fertilizer applications?

11. A bushel of carrots weighs fifty-six pounds. When analyzed, it is found to contain forty pounds of water and about two pounds of minerals (e.g., lime, potash, iron, sulphur, etc.). It obtains these substances from the soil. Would you therefore think that the carrot plant takes out of the soil about twenty times as much water as it does of mineral substances? Or considerably more? Or considerably less? Explain why.

12. Explain the difference, if any, between photosynthesis and photoperiodism.

13. To what extent and in what ways are the main objectives of pruning identical with those of fertilization, and to what extent and in what ways are they different? Explain fully.

14. (*a*) Would you expect a peach tree to manufacture the most carbohydrate during an average week in May or July or September? Why? (*b*) During which of these weeks would you expect the greatest net accumulation of carbohydrates? Why?

15. Make drawings to illustrate the various (progressive) stages in flower-bud differentiation, labeling parts. What are the principal factors that determine: (*a*) if they are to be differentiated at all, (*b*) where they are differentiated, (*c*) at what season they will be differentiated?

16. There is an old saying to the effect that "a stitch in time saves nine." Would you say that this applies with greater aptness to dealing with self-sterility in sweet cherries or to protecting flower beds from frost injury in the fall? Explain.

17. The nurseryman grows trees, shrubs, and vines to sell to the planter. The price he receives depends on their size. The purchaser of this nursery stock grows them principally for their flowers and fruits. What general or basic difference in (*a*) fertility of soil and (*b*) soil management (that is, in cultivation, irrigation, and fertilization) is called for in view of these different objectives? Explain fully.

18. Why are apples and pears usually propagated by means of grafting, tomatoes and cucumbers by means of seeds, and bananas and chrysanthemums by means of crown cuttings, instead of, say, apples and pears by means of seeds, tomatoes and cucumbers by means of cuttings, and bananas and chrysanthemums by means of graftage, *or* apples and pears by means of cuttings, tomatoes and cucumbers by means of graftage, and bananas and chrysanthemums by means of seeds? Explain fully.

19. Suppose you were going into the business of raising oranges in Florida or pecans in Georgia or English walnut trees in Oregon. Assume that you have already purchased suitable land and have it ready for planting. A nursery offers to sell you *budded trees* of a certain variety for

$2.00 apiece, or trees of the same variety and size grown from rooted cuttings at $1.75 apiece, or *seedlings* of the same variety and size for $.30 apiece. What are the specific questions you would seek to have answered before deciding which it would be wisest to purchase? Explain fully.

20. Does stock have greater influence on size or stature attained by the cion grafted on it or on the size of the flowers and fruits that it bears? How do you explain this?

21. To what extent and in what ways are stock and cion independent? To what extent, and in what ways are they interdependent? Explain fully.

22. In general, does the spraying of plants tend to promote or to retard rate of carbohydrate manufacture? Does it lead ultimately to less or to greater carbohydrate accumulation and storage? Explain fully.

23. Which of the following groups would you expect to require, on the average, the largest number of spray applications each growing season in order to afford them adequate protection — annuals, biennials, or woody perennials? Explain why.

24. If you were training tomatoes to single stems on stakes, would you break off the lateral branches and suckers while they are still very small, or would you let them make considerable growth before pruning them away? Explain why.

GLOSSARY

Abscission The process of becoming detached and falling, as of flowers, fruits, or leaves.

Absorption The intake of water or other substances, as by a cell, a root, or other plant organ.

Acid A condition in which the so-called *acid* elements (such as nitrogen, sulphur, or chlorine) in a solution overbalance the basic elements; associated with a greater concentration of hydrogen than of hydroxyl ions.

Activator A material that speeds up the action or increases the effectiveness of some other substance or preparation, as an insecticide.

Adsorption A surface phenomenon, in which water or other substances become spread out on or otherwise attached to particles of some other substance.

Adventitious An adjective applied to any bud not formed in the axil of a leaf or terminating a branch.

Aerophyte An air plant.

After-ripening A kind of curing process required by the seeds, bulbs, and related structures of certain plants before germination will take place.

Alkali A term used to refer to a condition of the soil or soil solution in which there is such a great concentration of certain salts that they become toxic to plants.

Alkalinity A condition in which the basic elements in a solution overbalance the acid elements, or a condition in which the hydroxyl (OH) ions outnumber the hydrogen (H) ions.

Anemophilous Pollen transferred by the wind.

Annual A plant whose normal life span does not exceed one year.

Annual ring The division line between the wood growth of two successive seasons.

Anthocyanin A group of plant pigments.

Arborescent A term applied to tree-like shrubs.

Arm A more or less horizontally trained branch of a plant.

Autogamy Self-pollination, without the aid of outside agencies.

Available water That portion of the soil moisture supply, mainly the capillary fraction, which the plant is able to absorb.

Availability Being in such physical form and chemical combination that it can be absorbed by plants.

Axillary An adjective applied to a bud found in the axil of a leaf.

Bactericide A material used to destroy bacteria.

Barren Nonfruitful.

Bast Long tough fibers found in the phloem of many plants.

Biennial A plant that normally lives more than one but not more than two years.

Bisexual A plant or variety that produces both staminate and pistillate flowers.

Bitter pit A disorder of apples in which small "islands" of tissue, irregularly distributed throughout the flesh, turn brown, become corky, and acquire a bitter taste.

Blanching Providing conditions under which growth is forced to take place in darkness, resulting in tissues or organs with little or no green coloring matter.

Blossom-end rot A disorder in which the tissues at the apical end of the fruit dry out, die, and become subject to decay.

Bolting The premature production of flower stalks, flowers, and seeds.

Bound water Water held tenaciously in the form of extremely thin films surrounding very small solid particles.

Bramble A term commonly used to include the cane fruits — raspberries, blackberries, dewberries, and related forms.

Bridge grafting Bridging over an injured area on stem, branch, or crotch by inserting the lower end of the cion between bark and wood below the area and its upper end between bark and wood above the area.

Bud A rudimentary or embryo stem.

Budding Usually defined as a method of graftage in which a single bud, with a little of the attached bark or bark and wood tissue, is used as the cion. More accurately, a method of graftage in which such a cion is so appressed against the stock that the cambium layers of the two can effect practically a complete union between the two — a union in which the entire appressed surfaces unite with each other.

Bulb A large fleshy, budlike structure.

Bulbel A small bulb produced above ground.

Bulblet A small bulb produced at the surface or below ground in the axil of a leaf or a bulb scale of a parent bulb.

Callus Tissue that has developed from exposed meristem and that is covering a wound.

Cambium Undifferentiated meristematic tissue in the form of a very thin layer between bark and wood.

Cane A branch, usually rather long and slender, of the preceding season's growth.

Canker A localized stem lesion in which the bark is killed and sometimes the underlying cambium and wood.

Capillary water Water held in the form of films surrounding the soil particles and partly filling the spaces between them, but not so tightly held that it is unavailable to plants.

Caprification The process of hanging flower clusters of staminate-flowered trees in trees of the pistillate-flowered kinds so that pollination can be effected.

Caprifig A fig tree or variety whose staminate flowers supply pollen for the pollination of pistillate-flowered trees.

Carbohydrate A compound of carbon, hydrogen, and oxygen in which there are twice as many hydrogen as oxygen atoms and either as many or one more carbon atoms as there are of oxygen.

Cell A structural unit, or "building block," in tissues of all kinds.

Cellulose The chemical substance that constitutes the bulk of the cell wall.

Chlorenchyma Parenchymatous tissue whose cells contain green coloring matter.

Chlorophyll The green coloring matter of leaves and other plant organs.

Chloroplast A plastid that contains green coloring matter or chlorophyll.

Chlorosis A disorder in which leaf tissues lose their normal green color and become yellow or white.

Cion The supported, or top, portion of a graft.

Cladophyll A stem that has assumed the functions and perhaps the shape of the leaf.

Cleistogamy Self-fertilization without the opening of the flower.

Colloid A material in a very finely divided state — that is, one in which the particles are extremely small.

Colloidally held water Water held tenaciously in the form of extremely thin films surrounding particles of colloidal size.

Compatibility A characteristic of flowers, plants, or varieties indicating that they are interfertile when the one is pollinated by the other. As applied to grafts the term indicates that the one may be successfully grafted upon the other.

Congeniality A term referring to the degree of success that can be realized when grafting one kind of plant upon another.

Coppice The reproduction of forest tree species that takes place through sprouting from stumps, crowns, and roots.

Corky core A disorder of apples in which the fleshy tissues of and around the core become dry and corky and sometimes bitter. Sometimes due to drought, sometimes to boron deficiency.

Corm A stem structure, somewhat resembling a bulb, but in which the main portion is stem and the scales or leaves constitute only a small portion of its bulk.

Cormel A small corm, usually produced from a bud in the axil of a parent corm's scale or leaf.

Corrective A material added to a spray material that reduces its possible injurious influence on the host plant.

Cortex The major part of the bark, especially its outer portion that is used primarily for storage purposes.

Cracked stem A disorder of celery, due to boron deficiency, in which the epidermal layer develops many cracks, and there is more or less browning of the internal tissues that become exposed.

Crown (1) The top of a tree, including its branches and that portion of the trunk from which the branches spring. (2) That portion of the plant's stem or trunk from a few inches above ground to a few inches below ground. (3) That portion of certain herbaceous plants that includes the short horizontal extensions or branches of the stem at or just below ground level.

Cuticle The thickened waxy surface layer of such plant organs as leaves, fruits, and shoots.

Cuttage Propagation by means of cuttings.

Cutting A severed portion of a root, stem, or leaf, used in propagation.

Cytoplasm The less dense, semi-liquid portion of the protoplasm.

Damping-off A disorder of young seedlings and of soft-wood cuttings in which the plant or cutting decays at the surface of the ground.

Deciduous Shedding its leaves each year and being without leaves during the winter or dormant season.

Deliquescent A type of stem growth exhibited by most deciduous trees, in which the branches outgrow the central axis or main trunk.

Derris A term often used in place of *rotenone*.

Determinate A term applied to those flower clusters whose terminal bud is a flower bud and often whose terminal flower bud is the first of its flowers to open.

Dextrin A more or less complex carbohydrate, related to starch.

Dextrose One of the simple sugars.

Dichogamy A characteristic possessed by some plants, and also some varieties, in which the stamens mature and shed their pollen at a different time than their pistils are receptive.

Dicotyledon A plant whose seeds contain two cotyledons or seed leaves. They have exogenous stems.

Dieback A killing back of shoots or branches, due to any one of several causes.

Differentiation Any change in shape, texture, or structure associated with growth.

Dimorphism A condition in which two distinct forms or types of growth are produced by a plant.

Dioecious A term applied to a unisexual plant or variety or to a species whose individual plants are unisexual.

Disbudding Removal of buds or of shoots or flowers just starting to develop from them.

Division Vegetative propagation in which the part that is used to start a new plant must be cut or forcibly broken away from the parent.

Dormant Not in an actively growing condition, but capable of resuming growth when environmental conditions become favorable.

Double working The regrafting, at a somewhat higher point, of an already grafted plant.

Dwarf A small-sized plant for its age but nevertheless one with normal vigor and healthy and not stunted.

Ecology That branch of a biological science which includes a study of relationship to other plants, animals, and to environment.

Embryo That portion of the seed that grows and develops into a plant, upon germination.

Endogen A plant in whose primary stem the vascular bundles are not arranged in concentric circles and whose older stems do not have distinct wood and bark layers.

Endosperm A portion of the seeds of certain plants lying alongside the embryo and consisting of slightly differentiated parenchyma stocked with food materials.

Entomophilous Pollinated through the agency of insects.

Enzyme An organic material that possesses the ability to promote certain chemical reactions without itself being appreciably used up in the process.

Epidermis The outer, protective surface layer of cells of root, stem, or leaf.

Epiphyte An air plant.

Eradication Absolute destruction, as by burning or deep burying.

Etiolation Growth in darkness or under very low light intensities, resulting in tissues and organs with little or no green coloring matter.

Excurrent The type of stem growth exhibited by most narrow-leaved evergreen trees in which the central axis continues more or less indefinitely to outgrow the lateral branches.

Exogen A plant in whose primary stem the vascular bundles are arranged in a circle near the outside and in whose older stems there are definite wood and bark layers.

Flush The growth that is produced during a short period.

Frenching A disorder in which the tissues between the veins and veinlets of leaves lose their green coloring matter, while the veins and veinlets remain green.

Fruit Botanically, a ripened ovary together with whatever may be closely attached to it. Horticulturally, the more or less fleshy, edible product resulting from the flower.

Fruitful Producing fruits, but not necessarily seeds.

Frutescent Shrublike.

Fungicide A material used to destroy fungi or protect plants against their attack.

Genus A group of usually several or many species that bear considerable resemblance to each other.

Glucose One of the simplest sugars, the one supposed to be the first product of photosynthesis and the starting point for the synthesis of more complex carbohydrates.

Graftage A method of propagation in which, characteristically, the root system of one plant is made to support the top of another.

Graft union The point of union between the two parts of a graft, the stock and the cion.

Hardening A process by which a plant or tissue is made more resistant to any extreme of environment — for example, low temperature, drought, intense light.

Hardiness A condition in which there is resistance to injury from low temperature.

Heartwood The darker colored wood toward the center of stem or root that has become physiologically inactive; it no longer functions for the transport of water and nutrients.

Hellebore An insecticide made from the dried and ground rootstocks of *Veratrum album*.

Hemicellulose A complex carbohydrate more or less intermediate between starch and cellulose.

Herbicide A material used to destroy weeds or other herbaceous plants.

Hermaphrodite A flower that has both stamens and a pistil, or a plant or variety whose flowers have this characteristic.

Homozygous Characterized by purity of line and fixity of type.

Hormone A growth-promoting substance.

Horticulture That branch of agriculture which deals with the intensive, as contrasted with the extensive, culture of plants. Garden culture.

Hybrid An individual resulting from the interbreeding of parents belonging to different species.

Hybridization The interbreeding of individuals belonging to different species.

Hydrolysis A process by which water is chemically combined with some other substance, usually resulting in rendering it soluble.

Hydrophyte A plant that grows in water.

Imperfect A flower that lacks either stamens or pistils.

Incompatibility A characteristic of flowers, plants, or varieties indicating that they are not interfertile when the one is pollinated by the other. As applied to grafts the term indicates that the one may not be successfully grafted upon the other.

Indeterminate A term applied to those inflorescences in which the lower buds are the first to be developed and to open and the number that forms is not predetermined, but depends on growing conditions. A shoot or stem that has no true terminal bud.

Infection Entrance, as of bacteria or fungus mycelium, into the tissues of the host.

Infestation Surface attack, as of an insect.

Inflorescence A flower cluster.

Insecticide A material used to kill insects or protect plants against their attack.

Intermediate The name given to the piece or kind that occupies the position between the root and the top in a double-worked tree.

Internode That part of a stem between two nodes or joints.

Inulin A carbohydrate closely related to starch.

Ion A fractional part of a compound, sometimes a single element but often a combination of two or more compounds having strong affinity for each other.

Isolation Keeping a plant or planting free from exposure to insect, disease, or other attack by so locating it that it cannot become infected.

June drop The term applied to the dropping of quarter- or third-grown fruits, that in some varieties and in some sections occurs in June.

Kniffin The name given to a system of training grapes in which one wire is placed vertically above another that it parallels.

Latent Not in an actively growing condition and ordinarily not able to resume growth when environmental conditions become favorable, though capable of doing so when subjected to some unusual stimulus.

Layerage A propagation method in which a portion of stem, shoot, or branch is covered with soil or some other medium in which roots can develop, after which the rooted portion is severed from the parent plant.

Lignification The process by which lignin or woody tissue is formed from simpler carbohydrates.

Lignin A complex, insoluble carbohydrate or group of closely related carbohydrates that constitute the main portion of woody tissue.

Little leaf A disorder, of the virus type or due to nutrient deficiency, in which the leaves are much dwarfed and sometimes more or less deformed.

Longevity The length of time during which a plant, seed, bulb, or other part used in propagation retains its ability to grow.

Mahaleb The name given to a strong vigorous type of cherry, closely related to the sour cherry, that is commonly used as a stock in the propagation of cherries.

Malling The name given to a numbered series of vegetatively propagated stocks used in the propagation of the apple that have been developed at the East Malling Research Station in England.

Manettii The name given to a strong vigorous type of rose that is often used as a stock in the propagation of cultivated rose varieties.

Mazzard The name given to a strong vigorous type of sweet cherry that is commonly used as a stock in the propagation of cherries.

Meristem Cellular tissue that has not yet undergone appreciable differentiation.

Mesophyll The interior tissue of the leaf.

Mesophyte An ordinary land plant that grows best where it is neither extremely dry nor extremely moist.

Monocotyledon A plant whose seeds

contains a single cotyledon or seed leaf. It produces endogenous stems.

Monoecious A plant or variety that produces both staminate and pistillate flowers.

Mottle leaf A disorder, sometimes due to nutrient deficiency and sometimes to a virus, in which the leaves show a mottled appearance occasioned by alternating or scattered areas of normal green and more or less chlorotic tissue.

Multiplier The name applied to a type of onion or other bulb that produces bulblets freely and is commonly propagated by means of them.

Munson The name given to a system of training grapes on horizontally strung wires.

Myrobolan The name given to a vigorous plum type native to central and southwestern Europe that is commonly used as a stock in the propagation of plums.

Nitrification The soil process by which nitrites are oxidized and changed into nitrates, through the aid of bacteria.

Node A joint; a point on a stem at which a leaf is attached.

Nucleus A comparatively dense portion of the cell's protoplasm that appears to be the center of its activity.

Nutrient A substance, such as water or a mineral compound, which the plant obtains from the soil and in due turn synthesizes into the more complex compounds of its own tissues.

Offset A large fleshy or semifleshy, scaly bud or rosette of leaves borne on a more or less horizontal, and usually short, branch.

Offshoot Any branch.

Osmosis An interchange of materials between two solutions separated by a membrane, resulting in approximately the same concentrations on both sides.

Ovicide A material used to destroy insect eggs.

Palisade The name given to the layer of elongated, columnar cells just beneath the upper surface of the leaf.

Paradise The name given to a dwarf growing variety or type of apple often used as a stock and that has a marked dwarfing influence on the cion varieties grown on it.

Parasite In a broad sense, a pest; in a narrower sense, an organism that weakens or destroys another by working within it.

Parenchyma Tissue in which the component cells have undergone comparatively little change in shape from their meristematic condition.

Pectin A carbohydrate to which the jellying properties of many fruits and other food products are due.

Pedicel The stem supporting an individual flower.

Peduncle The stem supporting a flower cluster.

Perfect A flower that has both stamens and a pistil.

Periodicity A characteristic of the growth of many plants or plant parts in which periods of rest alternate with periods of activity.

Perpetual A term applied to the flowering of certain plants in which flower production is not restricted to a short definite portion of the growing season, but is more or less continuous.

Petiole The stem or stalk of a leaf.

Phloem Vascular tissue in which food materials move from one part of the plant to another. In exogenous stems it constitutes the inner, conducting portions of the bark.

Photoperiodism The distinctive response of plants to exposures of daylight (or in some instances artificial light) periods of different lengths.

Photosynthesis The process by which green plants combine carbon dioxide, obtained from the air, with water to form carbohydrates.

Pip (1) A seed. (2) A fleshy, bulblike terminal bud of a rootstock.

Pistillate A flower that has a pistil but no stamens, or a plant or variety whose flowers have this characteristic.

Plastid A small, dense bit of protoplasm.

Plurannual A plant ordinarily grown as an annual but that survives for a longer period if conditions are favorable.

Pollination Transfer of pollen from stamen to stigma.

Polymorphic Characterized by considerable diversity of form.

Predator An animal that preys upon and eats another.

Pricking off The first transplanting given young seedlings.

Proliferation Excessive cell division at some point, resulting in an unusual enlargement of certain tissues or organs.

Protandry The condition in which the stamens shed their pollen before the pistils become receptive.

Protogyny The condition in which the pistils become receptive before the stamens shed their pollen.

Protoplasm A term that includes all of the living semisolid substance of the cell.

Pseudo hermaphrodite A flower that appears to be perfect but that is in reality unisexual, owing to abortive pollen or pistils, or a plant or variety whose flowers are of this type.

Pyrethrin The toxic principle of pyrethrum.

Pyrethrum An insecticide made from the dried and ground flower heads of *Chrysanthemum cinerariaefolium.*

Quarantine Protection by keeping infestation or infection away from the plant or the planting.

Quassia An insecticide made from the dried and ground wood of certain tropical species.

Quassin The toxic principle of quassia.

Ratoon An offset of the pineapple plant that springs from ground level or below and that characteristically forms roots before being separated from the parent plant.

Respiration The process of carbohydrate utilization by a living organism, with its attendant release of energy and liberation of carbon dioxide and water.

Rest period A time or period during which no increase in size is taking place, even though conditions seem to be favorable.

Rhizome Synonymous with *rootstock;* a nonfleshy, more or less horizontal underground stem.

Rogue An off-type individual.

Roguing The sorting out and elimination of off-type individuals.

Root hair A single-celled, elongated outgrowth from an epidermal cell of a very young root. The principal water- and nutrient-absorbing organ of the plant.

Rootstock Synonymous with *rhizome;* a non-fleshy, more or less horizontal, underground stem.

Rotenone An insecticide made from the dried and ground roots of several plants belonging to the legume family.

Runner A trailing branch that forms roots and rosettes of leaves at some of its nodes.

Sapwood The lighter-colored outer layer of wood that is still physiologically active and serves to transport water and nutrients from root to top.

Seed Botanically, a ripened ovule. Horticulturally, a young plant that is packed and ready for transportation.

Seminal Pertaining to seeds.

Separation Vegetative propagation by means of structures such as bulbels, tubers, etc., which are readily separated or broken away from the parent plant.

Setting A term applied to the process by means of which a flower starts to develop into a fruit.

Shifting Repotting, usually to a pot of larger size.

Shoot A branch, usually of the current season's growth and usually of at least medium length. Sometimes the term is applied to a branch of the preceding season's growth.

Shrub A woody perennial with strong growing branches springing from the crown or lower part of the stem and which in turn outstrip the central axis.

Site A particular piece of ground, characterized by a certain elevation, slope, drainage conditions, etc.

Sleeping A term applied to the flowers of certain plants that fail to open fully.

Slip (1) Any soft-wood cutting. (2) An offset of a plant, such as the pineapple, that develops just below its fruit.

Species A group of plants that resemble each other closely and that interbreed freely. The unit in the botanical classification of plants.

Spreader A material sometimes added to spray materials to improve their spreading qualities, usually by reducing their surface tension.

Spur A short branch, as compared with a shoot, which is longer.

Stabilizer A substance that when added to a spray material tends to keep it from deteriorating, breaking down, or settling out.

Staminate A flower that has stamens but no pistil, or a plant or variety whose flowers are of this type.

Starch One of the most common of the carbohydrates, relatively insoluble but more or less readily changed into less complex substances, including glucose sugar.

Sterility The characteristic of not being able to produce viable seed.

Sticker A substance sometimes added to spray materials to make them adhere better and longer to the surfaces to which they are applied.

Stipule A small bractlike structure at the base of the leaf stem, but a part of the leaf.

Stock The supporting part, including the root and sometimes more or less of the stem or even the stem and part of its branches, in a grafted plant.

Stolon A slender branch that bends over and takes root at or near its tip.

Stoma A specialized opening in the surface of the leaf, the size of which is controlled by its two surrounding guard cells.

Stool A cluster of shoots developing from the crown of a plant.

Stooling The practice of cutting back the stems of plants, covering them with soil, and thus forcing the new shoots that form to grow up through it.

Stratification Embedding in, or spreading between, layers of sand, soil, or some other medium.

Succulent A name given to a class of herbaceous plants with rather soft, fleshy nonwoody or only slightly woody stems or with thick, fleshy leaves.

Sucker A shoot developing from an adventitious bud on the root or rootstock.

Supernumerary An adjective applied to any bud other than the characteristic single one found in the axil of a leaf.

Taxonomy That branch of a science dealing with description, naming, and classification of types or kinds.

Tipburn Browning and death of tissues at the tips and along the edges of leaves or petals.

Tip layerage The practice of bending the tips of branches to the ground and covering them with soil so that they may take root.

Topiary A style of artificially training plants to resemble various objects such as birds, animals, men, etc. in shape.

Toxicant A specific substance or compound that gives some preparation or mixture in which it is carried its principal value as a poison of some kind.

Toxin Poison.

Transpiration The process in which water is released by the plant to the air in the form of water vapor.

Tree A woody perennial whose central axis outgrows its lateral branches, at least while young, and whose branches are plainly subordinate to its trunk.

Truncheon A stem cutting or section used in propagation that is of old wood and relatively large diameter.

Tuber An enlarged or fleshy rootstock.

Tubering The practice of covering stems or branches with a layer of soil or other medium so that the branches that grow up through it may take root. Such branches are etiolated and often have very short internodes.

Unisexual A flower that possesses, or a plant or variety that produces flowers that possess, only one of the two sex organs.

Vacuole A body or "lake" or occlusion of cell "sap," enclosed by surrounding cytoplasm.

Variegation A characteristic of the leaves of many horticultural varieties in which there is more or less of a characteristic pattern due to alternating or scattered patches, areas, or stripes of different colors.

Vascular tissue Tissue in which differentiation has resulted in tubular or ductlike cells that serve for water and food translocation within the plant.

Vegetative Pertaining to tissues such as leaves, roots, stems, and buds, as opposed to seeds.

Veratrine The toxic principle of the insecticide hellebore.

Vernalization A preplanting treatment sometimes accorded seeds in which they are placed under conditions favorable for germination for a short period and then are exposed to conditions where the germination process is arrested.

Viability The ability to germinate and grow.

Vine A plant whose stems and branches are so slender that they are unable to grow or remain erect without artificial support.

Vitality A term that applies to the presence of life in a seed, bulb, or other plant organ.

Viviparous A term applied to seeds that germinate before becoming detached from the parent plant or before being released from the fruit that surrounds them.

Watersprout A shoot developing from an adventitious or latent bud on the stem.

Wetting agent A material used to aid in wetting the surfaces of particles of such substances as sulphur or lead arsenate so that they can be better applied as a spray.

Wilting point The water content of a soil, expressed as percentage of the dry weight, at or below which permanent wilting of the plant occurs.

Xerophyte A plant adapted to growing in a region characterized by extreme drought.

Xylem Lignified, fibrous, and vascular tissue in which water and dissolved nutrient salts move upward from root to top. The woody portion of root and stem.

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Date Due

~~NOV 6 '51~~	Aug 4 54		
~~DEC 14 '51~~	Aug 6 54	APR [illegible] '61 CIRC	NO 13 '73
FEB 18 '52	Aug 9 54	NOV	2 RETURN
Apr23'52	Aug 10 54	CIRC DE	3 '73
Oct13'52	Aug 13 54	DEC	3 RETURN
NOV 30 '53		[illegible] CAM	FEB 10 '88
DEC 4 '53	DEC 18 '54	JAN 2	9 RETURN
APR 9 '54	JAN 6 '55	[illegible]-CAM	NOV 09 '89
APR 26 '54	April 10	OCT 3	0 RETURN
JUL 15 '54	april 11		
July 12	Apr. 12		
Jul 16 54	NOV 14 '55		
July 19	[illegible]		
Jul 21 54	DEC 19 '55		
Jul 22 54	DEC 16 '55		
Jul 26 54	Apr 19		
Jul 27 54	APR 2 [illegible] '56		
Jul 28 54	APR 23 '56		
Aug 2 54	[illegible] 4 '61		
Aug 3 54			
Aug 5 54			

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